

CONSTRUCTION OF THE SECOND 500 KV PHOTOCATHODE DC-GUN AT KEK

M. Yamamoto[#], T. Miyajima, Y. Honda, T. Uchiyama, M. Kobayashi,
KEK, 1-1 Oho, Tsukuba, Japan 304-0801

N. Nishimori, R. Nagai, S. Matsuba, R. Hajima,
JAEA, 2-4 Shirane Shirakata, Tokai, Naka-gun, Ibaraki, Japan 319-1195

M. Kuriki, Hiroshima Univ., 1-3-1 Kagamiyama, Higashihirosima, Hiroshima, Japan

M. Kuwahara, Nagoya Univ., Furo-cho, Chikusa-ku, Nagoya, Japan 4648603

H. Yoshida, AIST, 1-1-1 Umezono, Tsukuba, Ibaraki, Japan 305-8563

H. Kurisu, Yamaguchi Univ., Ube, Yamaguchi, Japan 755-8611

Abstract

A 500 kV photocathode DC-gun has been developed at KEK since 2009. The gun was almost completed and high voltage conditioning has been carried out up to 500 kV. In addition, we have designed a new quick cathode preparation system for a practical operation of the DC-gun without long interruption. The detail result and status are presented in this paper.

INTRODUCTION

A construction of compact-ERL (cERL) has been started in KEK and a 500 kV photocathode DC-gun (the first DC-gun) developed at JAEA has been installed in October 2012 [1-3]. The second 500 kV photocathode DC-gun has been developed at KEK since 2009 [4] not only for a substitution for the first DC-gun but also for a test machine for continuous R&D's on challenging issues because the second DC-gun can be operated independent of cERL.

Some main parts of the second gun system such as segmented insulator were designed to be compatible with the first gun. However, the second gun system has some new features. We have chosen TA010 (Kyocera) for the insulator, which is different from conventional Al_2O_3 material. Since TA010 is tolerant for surface discharge phenomenon in voltage condition higher than Al_2O_3 , we expect the second gun would reach the higher voltage and the higher electric field. In order to investigate a dark current and find a sign of discharge between anode and cathode electrodes in high voltage (HV) conditioning, an isolated anode plate was installed. In addition, a new pump system to generate extreme high vacuum (XHV) will be tested to maintain a long cathode lifetime. A repeller electrode was employed to protect the cathode from ion back bombardment since the electrode can reflect low energy ions which generated at downstream of the gun exit.

A 600 kV oil-impregnation Cockcroft-Walton high voltage power supply (HVPS) was tested up to 580 kV independently. The HVPS and the DC-gun system were connected through a SF_6 vessel (Fig. 1.).

A new cathode preparation system was designed for a practical operation of the DC-gun to compensate short

cathode lifetime in high-current electron beam generation. The preparation system can handle plural cathodes in parallel for cleaning, activation and storage.



Figure 1: A photograph of the second DC-gun. The HVPS (left) is connected to the gun chamber (right).

VACUUM SYSTEM

A DC-gun equipped with a photocathode of GaAs having a negative electron affinity (NEA) surface has advantages to generate a beam with low mean transverse energy and a high quantum efficiency. Therefore, a high voltage dc gun using an NEA-GaAs photocathode is one of the candidates for a high brightness electron source of ERL. However, the NEA-GaAs photocathode has disadvantage of a lifetime itself. The cathode QE degradation is dominated by back stream ions which are produced by collision between electron beams and residual molecules during high beam current operations. To improve the cathode lifetime, reduction of the residual molecules is essential. In order to achieve XHV better than 10^{-10} Pa, a chamber of the DC-gun system should have low outgassing property and vacuum pumps with a high effective pumping speed under XHV are indispensable. Generally, a combination of ion pump (IP) and non-evaporable getter (NEG) pumps is employed for

the main vacuum pump system of GaAs-based photocathode dc guns. Inert gases, which are not pumped by the NEG, are pumped by the IPs. However, the effective pumping speed of general IPs ordinarily decreases down to almost zero under XHV condition. Therefore, we employed a combination of bakeable cryopump [5] and NEG's for the main pump of the second DC-gun.

Outgassing Rate Measurement

Chemically polished titanium was chosen for a material of the main components of the gun vacuum chamber, guard rings, anode and cathode electrodes, because it achieves low outgassing rate [6].

A measurement of outgassing rate at the gun chamber was carried out in a situation that all vacuum components except the main vacuum pump system had been installed. Before the measurement, the system was baked at 150-200 °C for 100 hours. A total outgassing rate was measured by rate-of-rise (RoR) method using spinning rotor gauge (SRG) as shown in Fig. 2. The total outgassing rate of the system was estimated to be 8.1×10^{-11} Pa·m³/s equivalent for hydrogen.

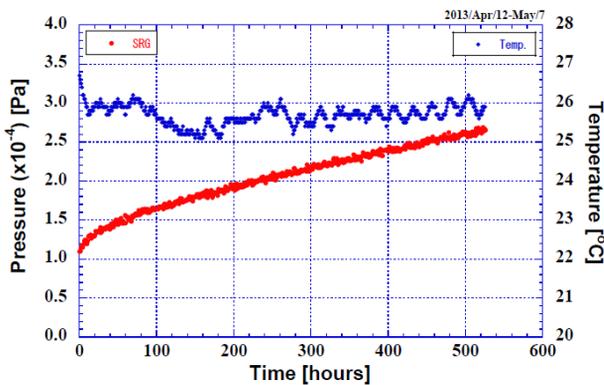


Figure 2: Result of rate-of-rise measurement of the second DC-gun system without the main vacuum pump system.

Pumping Speed of 4K Bakeable Cryopump

We employed a 4K bakeable cryopump, which has a G-M refrigerator spatially separated from a cryopump housing. This configuration enables one to bakeout the pump including cryopanel and adsorbent at a temperature above 150 °C, thus the pump has a potential to maintain high effective pumping speed even in the XHV. We measured a pumping speed of the bakeable cryopump using a standard conductance element for introducing test gas into a chamber accurately [7,8].

A result of the effective pumping speed measurement of the 4K bakeable cryopump is shown in Fig. 4, where the pumping speed was estimated from the pressure measured by extractor gauge. The pressure of each gas was converted using relative sensitivity factors that was calibrated at AIST. The pumping speed of CH₄, N₂, Ar, CO₂ were not significantly degraded under XHV

condition below 1×10^{-9} Pa, however the pumping speed measurement of hydrogen was restricted for a pressure above 1×10^{-9} Pa because of adsorption equilibrium of the charcoal for hydrogen in this situation. To improve pumping speed of hydrogen, degassing of charcoal by high-temperature baking is required.

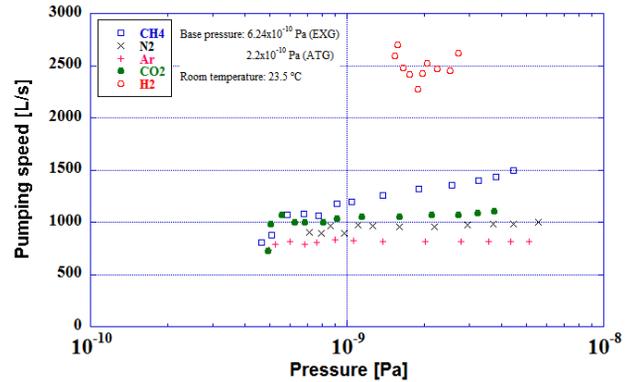


Figure 3: Result of pumping speed measurement at the 4K bakeable cryopump.

HV SETUP & CONDITIONING

High Voltage System Setup

After the measurement of outgassing rate, the gun chamber was evacuated again using a 1000 L/s turbo molecular pump (TMP) system for a high-voltage test. The main pump of the bakeable cryopump and NEG's was not installed at that time and a pressure in the gun chamber reached $\sim 1 \times 10^{-8}$ Pa in a few days.

To avoid discharge from the high voltage terminal and outside of segmented insulators, +0.2 MPa pressurized SF₆ gas was introduced to the vessel. In the HV conditioning mode, a resistor of 100 MΩ is connected between HVPS and the top of segmented insulator to avoid hard arcing inside the chamber. For the segmented insulators, 500 MΩ resistor is connected between each segment in series to obtain uniform electric field on the insulator surface.

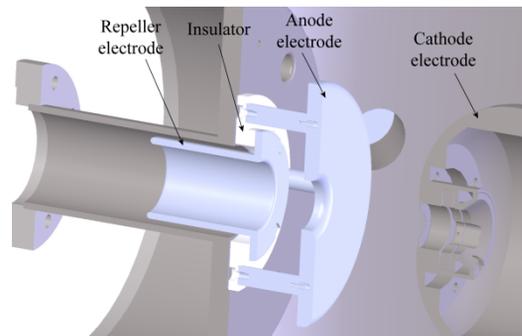


Figure 4: Cross-section view around the anode electrode.

In the gun chamber, anode and repeller electrodes were fixed with isolation from the ground level independently. (Fig. 4.) Since anode plate was fixed by four props, the anode-cathode gap can be tuneable (~ 110

mm at maximum) by exchanging the props. In this experiment, the gap was chosen at 70 mm.

2D cylindrical electric field around anode-cathode area was calculated by PISSON-SUPREFISH. The on-axis electric field $E_z(r=0,z)$ for a gun voltage of 500 kV is shown in Fig. 5. The field at the cathode center is 6.9 MV/m, and the maximum electric field on the cathode ball is around 11 MV/m.

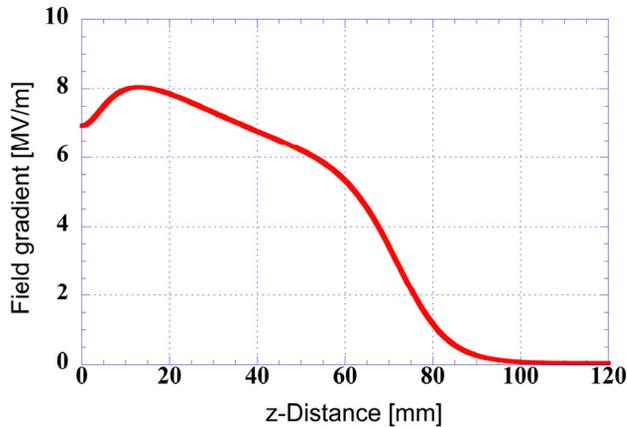


Figure 5: Calculate on-axis electric field in the second DC-gun for a gun voltage of 500 kV.

For the safety interlock of HVPS, we installed monitors: HVPS voltage, total supply current, a current of divide resistors, a dark current which flow between anode and cathode electrode and a load current which contain dark current from a cathode electrode and a high voltage terminal. Additionally, vacuum gauges of gun chamber and a radiation monitor were checked during the high-voltage test. These monitors help us to find troubles in the test. The interlock level were set to 500 nA for the anode current, 5×10^{-7} Pa for the vacuum, 20 $\mu\text{Sv/h}$ for the radiation. The HV output was turned off immediately when a value of monitors exceeded the interlock level.

High Voltage Conditioning

The result of HV conditioning is shown in Fig. 6. The chamber was evacuated by TMP during HV conditioning. The first HV trip to trigger the interlock happened at 300 kV, then HV trips happened over 350 times in 5 days conditioning. In this conditioning, all trips occurred in the vacuum side because the trips involved vacuum rising without any exception. From the interlock record, about 90% trips occurred between anode-cathode gap. In order to reduce X-ray dose during HV conditioning, the anode current monitor was useful since a response time of the anode current was faster than the other monitors.

After 350 times HV trips, a HV holding test at 480 kV was done for two hours. Some small vacuum trips and anode current trips were detected, however these levels were lower than the interlock level and no HV trip happened during the two-hour test.

A voltage stability of HVPS was monitored by using two methods independently in this HV test. One is a HVPS voltage monitor and the other is a current monitor

of ceramic divide resistor. The HVPS system needs a warm-up period about 1.5 hours to stabilize the output voltage, then it shows a good voltage stability better than 2×10^{-4} for two monitors.

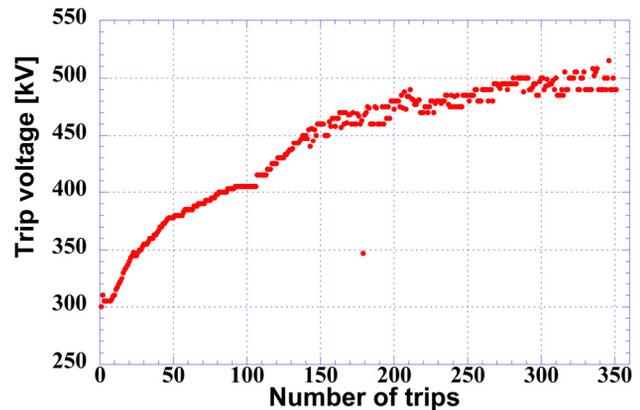


Figure 6: Result of HV conditioning.

CATHODE PREPARATION SYSTEM

An efficient cathode preparation system is important for a practical ERL electron gun, because a cathode lifetime becomes shorter for the higher beam current. Additionally, an NEA GaAs cathode is difficult to transferred by a vacuum suitcase, therefore a simultaneous three cathodes preparation system was designed as shown in Fig. 7.

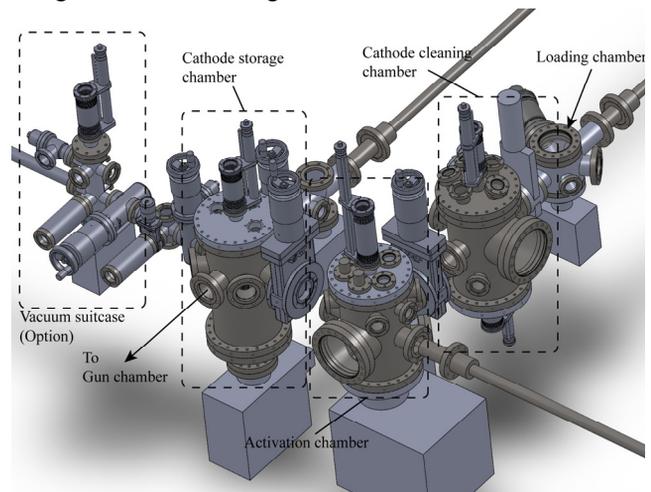


Figure 7: Schematic view of the cathode preparation system with simultaneous handling of plural cathodes for cleaning, activation and storage.

The preparation system consists of four sections: a loading chamber, cathode cleaning chamber, activation chamber and storage chamber. A cathode container that can mount three cathode is transferred between the loading chamber to the activation chamber. The system can treat three cathode containers, since 6~9 cathodes can be activated and stored in one day. Therefore, the system is effective to reduce a dead time to exchange cathodes during gun operation. Optionally, other type of cathode

such as a thin multi-alkali layer cathode can be installed to the storage chamber directly using a vacuum suitcase.

These vacuum chambers and components were almost fabricated and a vacuum test and motion check of cathode transfer system are in progress.

CONCLUSION

Construction of the second DC-gun at KEK was almost completed and HV conditioning was started. The outgassing rate of the DC-gun system was estimated at 8.1×10^{-11} Pa m³/s and the effective pumping speed of 4 K cryopump was measured in XHV condition. From these results, the pressure in the gun chamber can certainly reach to vacuum below 10^{-10} Pa. For electrodes in the gun chamber, a narrow anode-cathode gap of 70mm was chosen. In order to monitor a dark current between anode-cathode gap, the isolated anode electrode was employed. HV conditioning was carried out in this situation. The HV trip voltage exceeded 500 kV after 5 days conditioning, and a holding test at 480 kV was carried out for 2 hours with no HV trip. According to these result, a high voltage of ~500 kV and high electric field of ~7 MV/m on the cathode are feasible in the DC-gun system.

A simultaneous three cathodes preparation system was designed for compensating a short cathode lifetime in actual high current DC-gun operation. The vacuum components were almost fabricated and construction of the preparation system is in progress. Demonstration of efficient preparation and quick cathode exchange process at the second DC-gun is the next step.

ACKNOWLEDGMENT

We thank Professor H. Kawata, K. Satoh, H. Satoh and Y. Kobayashi of KEK for continuous encouragement for this work. We are also grateful to Associate Professor T. Obina and Mr. S. Nagahashi for contributions to build the HVPS interlock system.

REFERENCES

- [1] S. Sakanaka, et al., WG102, ERL2013.
- [2] R. Nagai et al., Rev. Sci. Instrum. **81**, 033304 (2010).
- [3] N. Nishimori et al., Appl. Phys. Lett. **102**, 234103 (2013).
- [4] T. Miyajima et al., FLS2010 presentation in WG5.
- [5] H. Yamakawa, Vacuum **44**, (1993) 675.
- [6] H. Kurisu et al., J. Vac. Sci. Technol. A **21**, (2003) L10.
- [7] H. Yoshida et al., Vacuum **86**, (2012) 838.
- [8] M. Yamamoto et al., TUODB02, IPAC2011 proceedings.