EXTREME HIGH VACUUM SYSTEM OF HIGH BRIGHTNESS ELECTRON SOURCE FOR ERL

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Abstract

A high brightness electron gun is under development to meet the requirements for the Energy Recovery Linac (ERL). The gun utilizes a gallium arsenide (GaAs) based photocathode to which a dc high voltage of 500 kV is applied, and requires an extreme high vacuum of below $1x10^{-10}$ Pa to preserve a Negative Electron Affinity (NEA) state on the cathode surface for a sufficiently long period of time under high current operation over 10 mA. All of the vacuum components in the gun system (a titanium chamber, a couple of ceramic insulators, guard rings, etc.) should have a low outgassing rate, and the pumps should function under the extreme high vacuum (XHV). In order to understand the actual performance of the vacuum system, we have precisely performed a measurement of the outgassing rate by rate-of-rise (RoR) method, as well as a pumping speed measurement of a bakeable cryopump using a standard conductance element.

INTRODUCTION

A photocathode dc gun using an NEA state on semiconductor cathode surface has advantages; a low emittance beam of less than 1 mm·mrad in the initial and a high quantum efficiency of about 10 % in the near-infrared can be achieved [1]. 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 photocathode with NEA state has disadvantage of a lifetime itself. The cathode QE degradation was dominated by back stream ions which are produced by collision between electron beams and residual molecules during high current operations. The charge lifetime, defined as integral extracted charge until QE drops to 1/e value of the initial QE, is limited to an order of 1000 Coulomb even at a pressure range of 10^{-9} Pa [2]. To improve the cathode lifetime, reduction of the ion bombardment is essential, and XHV is therefore required especially between cathode and anode regions.

In order to generate an XHV of less than 10^{-10} Pa, the electron gun system should be made of low outgassing materials, and the pumps should have a high effective pumping speed under the XHV. To obtain an assurance of XHV system in the actual dc gun system, measurements of a total outgassing rate from actual apparatus and a pumping speed under UHV to XHV have been carried out.

MEASUREMENT OF TOTAL OUTGASSING RATE

A 500 kV dc gun has been developed at KEK since 2009 with the cooperation of JAEA, Hiroshima Univ., Yamaguchi Univ., and Nagoya University. The gun design was based on the Cornell group's electron gun [3] and on feedback from 200kV dc gun developed for polarized electron sources at Nagoya University [4] and the JAEA 500 kV electron gun [5]. At present, main vacuum components of the gun system (a chemically polished titanium chamber [6], a couple of segmented ceramic insulator tubes, and guard ring electrodes) are fabricated and assembled as shown in Fig. 1.

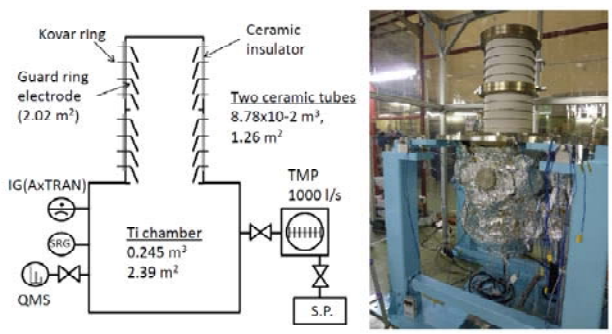

Figure 1: Schematic diagram of a presently assembled 500 kV DC gun vacuum system and its photograph.

Each component was baked out and a total outgassing rate was estimated individually before assembled. The titanium chamber was baked out at ~150 °C for 50 hours, and the segmented ceramic insulator tube was baked out at ~200 °C for 100 hours. These total outgassing measurements were carried out by RoR method using an ionization gauge since the measurement can be done quickly. The result of the total outgassing rate measurements after bakeout process is summarized in Table 1.

Then these components and guard ring electrodes were assembled as shown in Fig. 1, the system was bake out at 150-200 °C for 100 hours. The ultimate pressure in the chamber reached $7.2x10^{-9}$ Pa (equivalent for nitrogen) after the bakeout process. A total outgassing rate was measured by RoR method using spinning rotor gauge (SRG) as shown in Fig. 2. The total outgassing rate of the system was estimated to be $1.05x10^{-10}$ Pa·m³/s equivalent for hydrogen.

Table 1: Total outgassing rates of Ti chamber and segmented ceramic insulator tubes (w/o guard rings) measured by RoR method using an ionization gauge. The pressure was estimated for hydrogen.

Component	Baking No.	
	#1	#2
Titanium chamber	3.17×10^{-10}	2.65×10^{-10}
Ceramic tube #1	9.64×10^{-10}	5.89×10^{-10}
Ceramic tube #2	6.52×10^{-10}	4.73×10^{-10}

Unit: Pa·m^3/s

The total outgassing from these main components is quite low although the system includes the ceramic tubes and additional electrodes of guard rings. It indicates that the total outgassing rate can be suppressed by the adequate brazing, welding and surface treatment together with employing low outgassing materials.

From the comparison of the results between the SRG measurement and the ion gauge measurements (summing up the outgassing from each component), the total outgassing rate after assembled was lower by a factor of about 10. It seems that the outgassing from the ion gauge and its housing would be dominant in the individual measurements.

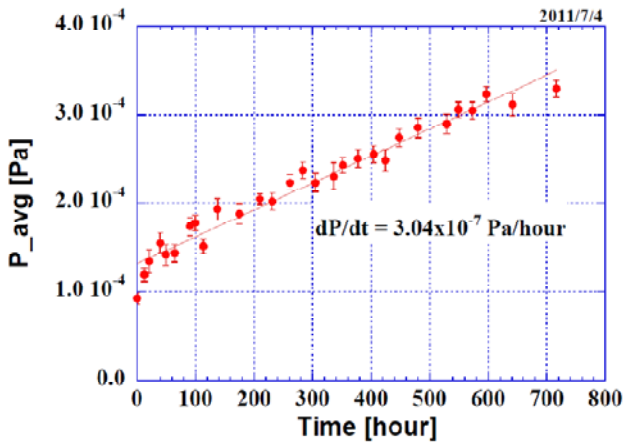

Figure 2: Raw data of the RoR measurement for assembled dc gun system by the SRG for about 1 month. The value of pressure is equivalent for nitrogen.

MEASUREMENT OF PUMPING SPEED OF BAKEABLE CRYOPUMP

A vacuum system which has a function of high effective pumping speed under XHV is also essential. Generally, a combination of ion pump (IP) and non-evaporable getter (NEG) pumps are 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 ~~are~~ ordinarily decreases down to almost zero under XHV below 10^{-10} Pa. A bakeable cryopump, which is separated G-M refrigerator spatially from cryopump housing in order to bakeout the pump including cryopanels and adsorbent at a temperature of above 150 °C, has a potential to maintain high effective pumping speed in the XHV [7]. Therefore, the bakeable cryopump is employed for the main pumping system together with the NEG pumps.

The pumping speed S [m^3/s] is defined as

$$S[\mathrm{m^3/s}] = \frac{Q\ [\mathrm{Pa\cdot m^3/s}]}{P\,[\mathrm{Pa}]} \qquad (1)$$

Where Q [Pa·m^3/s] is the amount of gas flow which is contained in a total outgassing rate of the vacuum system, and P [Pa] is the pressure in the chamber. A pumping speed measurement of a 20 K bakeable cryopump was carried out tentatively to establish feasibility of the system in the ultra high vacuum (UHV) condition. The apparatus is composed of three parts of the 20 K bakeable cryopump, a test chamber made of titanium, and a gas introduction system, as shown in Fig. 3. The pressure in the test chamber is measured by an extractor gauge (EXG) and an axial symmetric transmission gauge (ATG) [8].

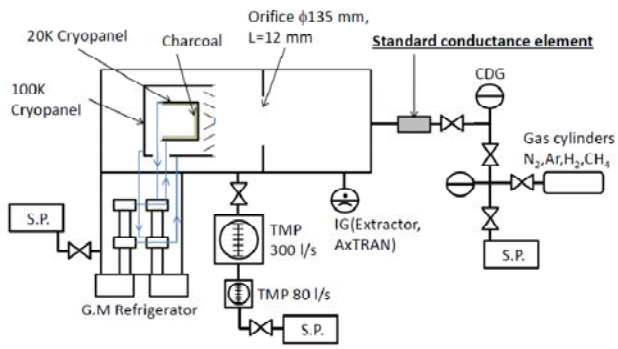

Figure 3: A 20 K bakeable cryopump and a pump speed measurement system with a precise gas flow control system using a standard conductance element.

In order to accurately control the gas flow to the test chamber, a standard conductance element made of sintered stainless steel filters with a nominal pore size of less than 1 μm was employed [9]. The gas flow Q [Pa·m^3/s] through the standard conductance element is estimated as

$$Q[\mathrm{m^3/s}] = P_f\,[\mathrm{Pa}]\cdot C[\mathrm{m^3/s}]\sqrt{\frac{28}{M_a}}\sqrt{\frac{T[\mathrm{K}]}{T_0}} \qquad (2)$$

Where P_f [Pa] is the pressure in the inlet of the element measured by a capacitance diaphragm gauge (CDG), M_a is the molecular mass of introduction gas, T [K] is the temperature of the element, C [m^3/s] is the experimentally determined conductance of the element for nitrogen at the temperature T_0. The conductance was proofread within 6% error by AIST. The element which has a conductance of 3.01×10^{-10} Pa m^3/s at the temperature of 300.5 K was used in this experiment.

The pressure dependence of the effective pumping speed was estimated as

$$S_{(P)} = \frac{Q_{(P_f)}}{(P - P_0)/\alpha} \quad (3)$$

Where P_0 is the base pressure before beginning of gas introduction, α is a relative sensitivity factor of an ion gauge. The values of α of ATG and EXG for hydrogen, methane and argon are shown in Table 2.

Table 2: Typical relative sensitivity factors of ATG and EXG for hydrogen, methane and argon. The values were measured by a calibration system at AIST [10].

	ATG	EXG
H_2	0.48	0.45
CH_4	1.69	1.56
Ar	1.43	1.41

The bakeable cryopump and test chamber were pumped by turbo molecular pumps (TMP) of 300 L/s and 80 L/s in series during bakeout process. The base pressure of the test chamber reached about $1x10^{-7}$ Pa after the bakeout at 200-230 °C for 80 hours. After operating G-M refrigerator for more than 6 hours and TMP was separated from the system, the base pressure reached $1.2x10^{-9}$ Pa.

A result of the effective pumping speed measurement of the 20 K bakeable cryopump is shown in Fig. 4. The result was estimated from the pressure measured by ATG. A result estimated by EXG has almost the same tendency of the result of Fig. 4 with a decrease of 10±1 % for nitrogen in the range of 10^{-7} to 10^{-8} Pa. The gas was introduced in order of nitrogen, argon, methane, and hydrogen. The pressure in the inlet of the element measured by CDG was controlled from 1000 Pa to less than 10 Pa in this experiment. Each measurement was obtained after the test chamber and gas introduction system had been pumped down sufficiently.

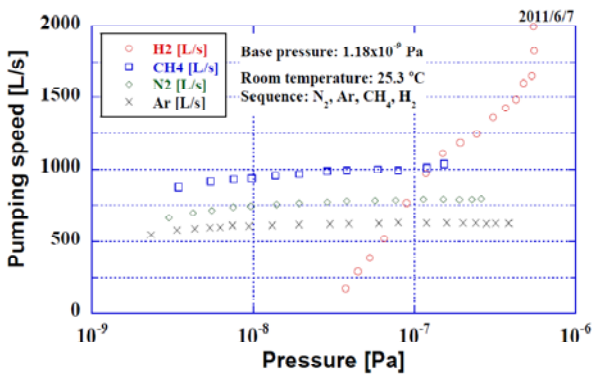

Figure 4: Result of the pumping speed of the 20 K bakeable cryopump for hydrogen, methane, nitrogen and argon.

A pumping probability is calculated by the ratio of the number of pumped molecules N_p to the number of incident molecules N_0 from the result of pumping speed and the conductance of exhaust port (ϕ135mm, L=12mm orifice) of the cryopump, and is almost the same value (N_p/N_0~0.5) for nitrogen, methane and argon. The result indicates that these molecules are pumped efficiently by cryo-condensation or cryo-sorption effect under UHV condition. However, the pumping speed for hydrogen decreased quickly in the regime below 10^{-6} Pa. It seems that the ultimate pressure is limited by the adsorption equilibrium of the charcoal for hydrogen [11]. In order to improve capability of the pumping speed under XHV, the cryopump should be operated at lower temperature of less than 10 K, or more degassing of hydrogen from the charcoal by high temperature and long term bakeout process might be required.

CONCLUSION

The basic measurements of a total outgassing rate of the actual 500 kV electron gun and a pumping speed of 20 K bakeable cryopump have been carried out to understand feasibility of generating XHV for the actual system.

The total outgassing rate of the 500 kV electron gun which consists of the chemically polished titanium chamber, the ceramic insulator tubes, and the guard ring electrodes were measured by RoR method using SRG. The pressure rose linearly for 1 month, and very low total outgassing rate of $1.05x10^{-10}$ Pa·m^3/s was estimated.

The pumping speed measurement system which uses the standard conductance element was established. A pumping speed of the 20 K bakeable cryopump was obtained for nitrogen, argon, methane, and hydrogen. The ultimate pressure of 20 K bakeable cryopump was limited to about $1x10^{-9}$ Pa by adsorption equilibrium of hydrogen in this experiment.

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