DEVELOPMENT OF A PHOTOCATHODE TEST BENCH USING A CRYO-PUMP AND A NEG PUMP*

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Abstract

The Beam Physics Laboratory of Hiroshima University studys photo-cathode for future acceleators by using a photo-cathode test bench. It aims to develop a cathode with the higher quantum efficiency and longer-lifetime. GaAs with Negative Electron Affinity (NEA) surface is one of the best cathode among the advanced cathode matrials. The NEA surface is essential to activate it as an electron source. It is well known that the NEA GaAs photo-cathode needs extremely high vacuum, because it is easily damaged. To study the detail process of the cathode property degradation by the damage, we construct a photo-cathode test bench with an extremely high vacuum quality based on a cryo-pump (2700l/s) and a NEG pump (1900l/s). The vacuum chamber is made of titanium (TP340) for low outgassing rate. We alredy obtain 1.7E-9Pa only with the cryo-pump. In this article, the test bench is briefly explained and the results of the first vacuum test is presented.

INTRODUCTION

There are several future accelerator projects based on linac, e.g. International Linear Collider (ILC) [1], Compact Linear Collider (CLIC) [2], Energy Recovery Linac (ERL) [3], Free Electron Laser (FEL) [4], etc. In these accelerators, electron source is one of the most important components, which decides the total performance. For example, ERL requires high average current up to 100mA with an extremely low emittance down to 0.1mm.mrad [3]. The strong candidate for the future ERL light source is the combination of a DC gun and NEA cathode. NEA surface is made by evaporating cesium and oxygen on a crystal of p-type GaAs. As the NEA is made from weakly bound cesium and oxygen, it is easily degraded or destroyed by absorption of impurity atoms and back-bonbardment of positive ions produced by collision of electron beam with residual gas molecules. So far, the cathode has a finite operational lifetime. The lifetime of the cathode can be improved with a better vacuum[5]. This experiment was carried out with an existing photo-cathode test bench at Hiroshima University. The photo-cathode test bench is kept in ultra high vacuum (UHV), routinely 5.0E-9Pa. To study the detail of the cathode degradation mechanism, the environment has to be controlled artificially in a wide range of various parameters. One of the most important parameter is the vacuum pressure. For example, to qualify the damage by various kinds of residual gas, the base pressure should be suppressed significantly lower than that of the artificially introduced target gas molecule. Of course, demonstration of an even enough long operational lifetime under various conditions is another goal. For such purposes, we are developing a new photo-cathode test bench with a bettter vaccuum than that of the exisiting system.

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DEVELOPMET OF PHOTO-CATHODE TEST BENCH

The existing photo-cathode test bench (System No.0) consists from vacuum chamber made from chemically polished SUS, Ion pump (160l/s), NEG pump (310 l/s), Q-mass, gate valve for rough pumping by TMP (Turbo Molecular Pump), and equipments for GaAs cathode activation. GaAs is embedded on molybdenum plate fixed by Ta foil.Indium paste is placed between the molybdenum plate and GaAs wafer for a good thermal conductivity. In the system No. 0, the base pressure is 5.0E-9Pa or lower. In such ultra-high vacuum region, Ion pump might be a source of outgas rather than an effective pump because the pumping speed could be quickly decreased in the ultra-high vacuum.

To design a new system, we consider replace the ion pump with a cryopump, because the saturated vapour pressure for ordinal gas molecules at the extremely low temperature around 10K, temperature of the cryo-panel, is less than 1E-10Pa and a significant pumping speed is expected still in such ultra-high vacuum region. The new system (System No.1) is designed with the main pump system of the cryopump and NEG pump. In addition, the chamber is made from chemically polished titanium for low out-gassing rate comparing with SUS. Out-gassing rate of titanium is better than stainless steel. Kurisu et al. reported that the out-gassing rate of the titanium which was baked for 20 hours at 200 °C was 7E-13Pa·m/s [6].

The overview of the system No.1 is shown in Fig. 1. It consists of a beam chamber and a loading chamber. The beam chamber and the loading chamber are separated by an all-metal gate valve.

The beam chamber has a function of a testing photo-cathode in extremely high vacuum. The beam chamber is made from chemically polished titanium as mentioned already. It has cryopump and NEG pump as the main pumping system. TMP (300l/s) is connected to the main

chamber through a metal angle valve for rough pumping at start up and baking, and NEG activation. An extractor gauge (EXT) for vacuum pressure measurement and optical view ports for laser introduction are implemented. One of the main vacuum systems is the NEG pump. It is activated by heating for forty-five minutes at 450°C. The NEG pump has high pumping speed for hydrogen which is the main component of the residual gas at ultra-high vacuum. The pumping speed to the hydrogen of the NEG pump is expected to be 1900l/s. However, the NEG pump is not effective to pump the rare gas and the methane gas. The cryo-pump is employed to recover this deficiency. The cryo-pump is bakable at 200°C. According to the maker specification, the pumping speed to the hydrogen of the cryo-pump is 2700l/s, to the argon is 1400l/s.

For beam generation experiment, laser light is irradiated from the optical window in front of the beam chamber. The beam chamber is made of titanium (TP340) and the inner surface was finished by chemical polishing. To improve the vacuum performance further by introducing titanium, the cryo-pump body is made from titanium instead of SUS.

The loading chamber has functions of cathode loading, heat cleaning, and NEA activation. It consists of a tungsten heater, optical windows, sources of cesium and oxygen, a transfer rod, a cold cathode gauge (CCG), and a vacuum system. GaAs cathode mounted on a cathode puck and installed to the loading chamber. The cathode puck is then heated by using the heater for 1 hour at 550°C. The temperature is monitored by a radiation thermo-mater over the optical window. This heating process is called heat cleaning and prepares the surface for the following NEA activation process. The main vacuum system of the loading chamber is the ion pump. A TMP is used as a roughing pump. The CCG is used to measure the vacuum in the loading chamber in a range from 2E-7Pa to 1E-0Pa, and can be baked at 250°C. The loading chamber is made of SUS finished by chemical polishing.

The GaAs cathode is then activated by Yo-Yo method by evaporating Cs and Oxygen on GaAs surface by monitoring photo-current. After the activation, the cathode is transferred to the beam chamber by using the transfer rod through the all-metal gate valve.

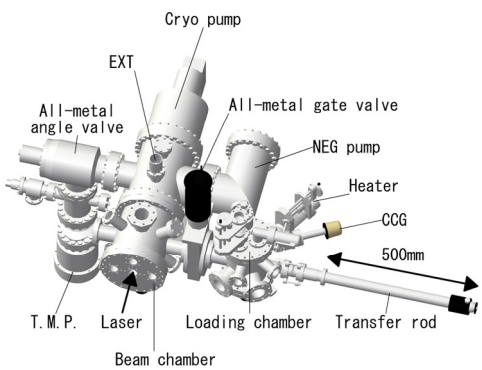

Figure 1: A schematic view of a new photo-cathode test bench.

RESULTS AND DISCUSSION

The construction of the system No.1 is finished only for the beam chamber part. TMP, cyro-pump, NEG pump, and EXT are connected to the beam chamber and other ports are sealed by blank flanges. In this simple configuration, we perform tests of the vacuum property of the system.

At first, the chamber is pumped by TMP. After some period, the vacuum pressure is saturated typically at 9.4E-5Pa. The baking process is then started. The baking is performed by sheath and ribbon heaters surrounding the chambers. Applied voltage to the heaters is manually controlled to keep the temperature time gradient and geometrical gradient low. The temperature time gradient is kept less than 20K/hour during the baking process.

The vacuum baking test were performed twice, once in 70°C, and once in 200°C as the maximum baking temperature. The reason why we did two different tests, is that temperature of a part of the cryopump should not exceed 70°C. Therefore, as long as the cyropump is not operated, the actual maximum baking temperature is 70 °C. Once the cryopump is in operation, the part is cooled by the cryogenic refrigerator and the body can be baked up to 200 °C. Then, the two modes of the baking corresponds to the baking tests with and without cryopump operation.

Figure 2 shows the evolution of a vacuum pressure, a temperature of the chamber and the cryo-pump during the baking tests. The NEG pump is not yet implemented in these tests.

Figure 2 (a) is result of 70°C baking. First, the chamber was baked for 65 hours at 70°C. During the bake-out, the vacuum was typically 3E-5Pa pumping with the TMP. When the chamber temperature returned to the room temperature (22°C), the vacuum was 2.5E-7Pa in the chamber pumping with the TMP. The cryo-pump was started at 91 hours from the start. According to the ULVAC (company of the cryopump) catalogue, the cryo-pump has a significant pumping speed when the thermal-shield of the cyropump is reached at -143°C. Then, the angle valve was closed when the shield reached at the temperature. The residual gas in the chamber is evacuated only the cryopump after this point. First, the vacuum pressure is rapidly decreased down to less than 1E-8Pa as shown in Fig. 2(a), but there is a kink on the vacuum curve at 90 hours from the start and the pumping speed becomes much slower than that period. The vacuum pressure was finally reached down to 1.7E-9Pa at 300 hours from the start.

Figure 2(b) is result of 200°C baking. First, the chamber was baked for 33 hours at 70°C. The vacuum pressure was typically 2.2E-5Pa pumping with the TMP. Second, the chamber was baked for 120 hours at 200 °C. During the bake-out, the cryo-pump was operated to keep the temperature of the thermal shield less than 70°C. After 120 hours of the 200°C baking, the chamber temperature was lowered by reducing power to the heaters. When the thermal shield temperature was reached

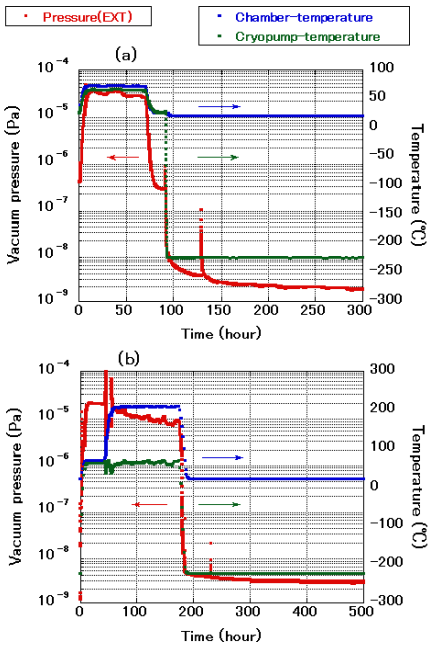

Figure 2: Results of a vacuum test. (a) is 70°C baking, (b) is 200°C baking. Vacuum pressure (left axis) and temperature (right axis) are shown.

to -143°C, the chamber body temperature was 80°C. Because a significant pumping speed expected, the angle valve was closed and the chamber is evacuated only by the cryopump as same as that in 70°C case. The vacuum pressure is rapidly decreased down to less than 1E-8 Pa in 183 hours, but after 317 hours, the pumping speed becomes much slower as same as that in 70°C case, but the change on the pumping speed was more drastic. Finally, the vacuum pressure was reached to 2.8E-9Pa at 400 hours.

The property of the pumping curve, e.g. there is a kink in a range of 1E-8Pa, the kink place (pressure) is different for (a) and (b), the change is larger for (b), etc. are not understood at all. It might be characterized by a two components model and the amplitude of these two components might be changed by the baking process.

If the final vacuum pressure for both cases is in saturation between the outgas from the vacuum chamber and the pumping and the outgas rate can be measured by other experiment, we are able to estimate the pumping speed of the cryo-pump in UHV. To estimate the out-gassing rate, we perform a build up test of the vacuum chamber. After a 70°C baking for 1 hour with pumping by TMP, the gate-valve is closed and the vacuum pressure evolution is observed. Figure.3 shows the time evolution of the vacuum pressure. The gate valve is closed at t=110. The out-gassing rate is estimated from the gradient of the curve from t=120 to t=300 and it was 3.2E-9 Pa/s. The volume of the chamber is 0.015m^3 and the inner surface area of the chamber is 0.41m^2. By using these numbers, the out-gassing rate is expected to be, 1.1E-10Pa·m/s. Assuming the out-gassing rate is common for all cases, the pumping speed of the cryo-pump is estimated to be 28l/s for 70°C case and 17l/s for 200°C case. The pumping speed of the cryo-pump specified in the company catalogue is 2700l/s for hydrogen and it was confirmed that the actual speed is much decreased in UHV.

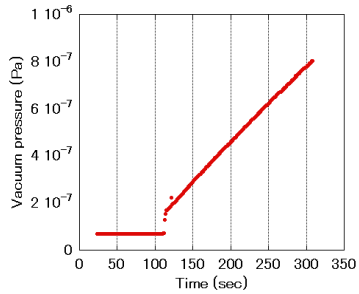

Figure 3: Results of a build up test.

SUMMARY AND FUTURE PLANS

A photo-cathode test bench based on a cryo-pump and a NEG pump was designed. As a result of the vacuum activation test, 1.7E-9Pa was established with only cryo-pump. We evaluated the pumping speed of the cryo-pump under UHV and the pumping speed of the cryo-pump was found to be 28l/s and 17l/s for different activation process. It was confirmed that the pumping speed is much less than the specified number in the catalogue, but some improvement can be expected by introducing additional pumping by NEG. If the system works well, extremely ultra-high vacuum, 1E-10Pa or less, could be stably established.

First of all, we have to understand the pressure evolution of the cryopumping. As a result of the detail analysis, the exact out-gassing rate and the actual pumping speed can be extracted from the data. By comparing these numbers among different activation methods, we are able to optimize the activation process from the high vacuum operation point of view.

Once the ultra-high vacuum is stable reproduced by the new system, we can perform the cathode activation and lifetime measurements in the new system.

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