DEVELOPMENT OF 200 KeV POLARIZED ELECTRON SOURCE

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Abstract

A 200 keV polarized electron source with a load lock system has been developed to produce high peak current and low emittance beam to satisfy various requirements of future e^+- e^- linear colliders. The components of this system were almost constructed and the performance tests are in progress. The dark current between the accelerating electrodes of the gun must be reduced to a level of less than 20 nA to assure a long lifetime of the Negative Electron Affinity (NEA) surface of the photocathode. The successful result was obtained for this issue, which achieved an extremely low dark current of < 0.1 nA at a DC high voltage of 200 kV.

1 INTRODUCTION

Nowadays, polarized electron beam has been used for the spin physics programs at Bonn, Mainz, MIT/Bates, SLAC and TJNAF [1]. It is also expected that a polarized electron beam will take an essential part for an electron injector of e^+- e^- linear collider, such as Japan Linear Collider (JLC).

The polarized electron beam is produced by photo-emission from the GaAs-type semiconductor photocathode with an NEA surface. The NEA surface is made by both of the band bending at the heavily p-doped surface and the electric dipole field of a Ga^--Cs^+ monolayer formed by deposition of cesium and oxygen atoms [2][3].

A high field gradient gun is indispensable for linear colliders. It makes possible to produce the beam that satisfies two conflicting performances, high-intensity and low-emittance, since the current density limited by space charge effect becomes higher and the beam divergence caused by space charge force is suppressed by relativistic effect.

The electron source for C-band linac scheme of JLC must produce 72 micro-bunchs with a bunch separation time of 2.8 ns and each micro-bunch must contain 2×10^{10} electrons in ~ 700 ps bunch width, which corresponds to about 3 A peak current [4]. The required normalized emittance at the gun exit is ~ 10 π mm mrad (r.m.s.).

We have demonstrated that the DC gun with a superlattice photocathode can produce such a beam overcoming the NEA surface-charge-limit phenomenon [5][6]. However, in this experiment the gun bias voltage was limited below 70 kV and thus the peak current was limited to be 1.6 A by space charge effect. The gradual increase of the dark currents, which was caused by cesium atoms accumulated on the electrodes during the repetitive

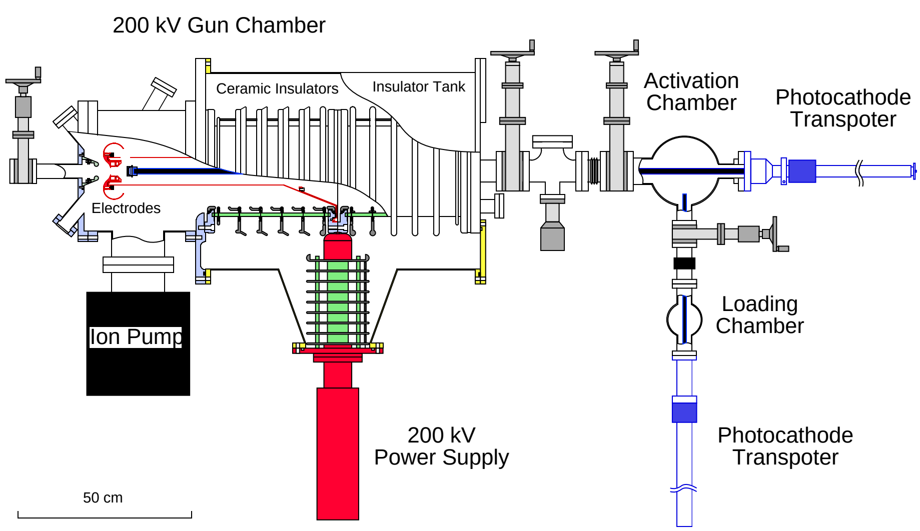

Figure 1: Schematic view of the 200 kV polarized electron gun system.

NEA activation process, did not allow the operation of the gun at higher voltage. The desorbed gas from the electrodes due to the dark current will be ionized by the electron beam itself and the back-bombardment of these ions cause the degradation of the NEA surface.

In order to overcome this problem, a new DC high voltage (HV) gun with a load-lock system has been constructed.

2 THE POLARIZED ELECTRON SOURCES

2.1 Load-Lock System

The schematic view of the new polarized electron source is shown in Figure 1. It consists of three vacuum isolated chambers: a photocathode loading chamber, a photocathode activation chamber and a HV gun chamber. The photocathode can be transferred between the chambers by using two transporters without breaking the ultra-high vacuum (UHV). A photocathode can be installed to the loading chamber from atmosphere and cleaned by atomic hydrogen method [7]. Heat cleaning by RF induction heating method and NEA activation of the photocathodes are done at the activation chamber. Finally, the photocathode is installed to a center of the cathode electrode in the gun chamber, which has axial symmetric geometry to the beam line. To avoid the increase of dark current, the cesiation is done only in the activation chamber.

2.2 High Voltage Insulation

In order to operate the load-lock system at grand level, the HV is supplied to a central flange of two ceramic insulator-columns (see Figure 1) and the cathode electrode support tube is fixed to this flange. Each ceramic insulator is divided into five segments and five 500 MΩ divider resistors are used for HV distribution. The maximum voltage of a HV power supply is 250 kV, which is used for aging the electrode surface to assure the stable operation at 200 kV.

All HV components are enclosed in the insulation gas tank. Dry nitrogen gas is flowed into the tank to remove the humidity in air to decrease the leakage currents along the ceramic surface, and then it is pressurized to suppress the corona discharge.

2.3 Accelerating Electrodes

A cross section and an equipotential of the accelerating electrodes are shown in Figure 2. The cathode-anode gap distance and the photocathode diameter were chosen to be 35 mm and 18 mm ϕ respectively. The space-charge-limited current at 200 kV in the case of full laser illumination was estimated to be about 30 A using the simulation code of EGUN. This value is enough high to satisfy the charge requirement of JLC.

To reduce the dark current of accelerating electrodes, the curvature of the cathode electrode was enlarged (~ 30 mm) so that the field gradient become smaller. The field gradient on the photocathode and the cathode electrode surface at 200 kV were estimated to be 3.0 MV/m and 7.8 MV/m at maximum using the simulation code of POISSON.

It is well known that the dark current level must be kept below 20 nA to preserve high quantum efficiency of the NEA surface. Non-metallic impurities on the electrode surface would become the emitting sites of the dark current. Therefore, the fabrication procedure of the electrodes is so important to reduce the dark current. A basic research on this issue was made using a test-apparatus build at KEK [8]. To reduce the non-metallic impurities, the super-clean stainless steel made by remelting method was used as an electrode material. Surface polishing by electro-chemical buffing method and the subsequent rinsing with ultra-pure water were also employed to remove the contamination or dust on the electrode surface. As a result, the dark current from the test electrode with an area of ~ 7 mm^2 could be reduced to ~ 90 pA under a high field gradient of 34 MV/m. This technique has been applied to fabricate the accelerating electrodes of the present 200 kV gun.

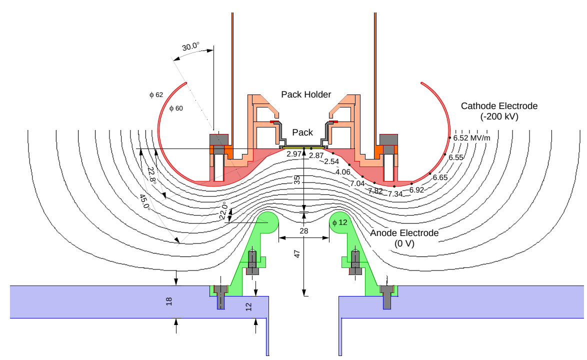

Figure 2: Accelerating electrodes (Unit: MV/m).

3 ULTRA-HIGH VACUUM

At the gun chamber, UHV is especially important to maintain the good NEA state. The gun chamber has two main pumps: 360 l/s ion pump and 850 l/s NEG pump. During the baking process, the temperature was ramped up or down at the rate of ± 4 °C/ hour to avoid the mechanical breaking of ceramic insulators due to the different thermal expansions between metal and ceramics. After baking at 200 °C for 100 hours, the total pressure at room temperature decreased to 3.5×10^{-11} torr which was monitored by an extractor gage.

4 HIGH VOLTAGE TEST

In order to measure the field emission dark current (I_f) produced by accelerating electrodes, this current must be distinguished from the other discharge currents caused by various HV elements. For this purpose, both of the HV power supply and the insulation tank are electrically isolated from ground. The discharge current generated at the corona rings is collected in the insulation tank and goes to ground through a current meter (I_d). The loop current that flows the divider resistors returns to the HV power supply without passing through ground. I_f and I_d, which are isolated from this loop, go to ground and then come back to the HV power supply through another current meter (I_t). Therefore, I_f can be estimated simply as $I_f = I_t - I_d$.

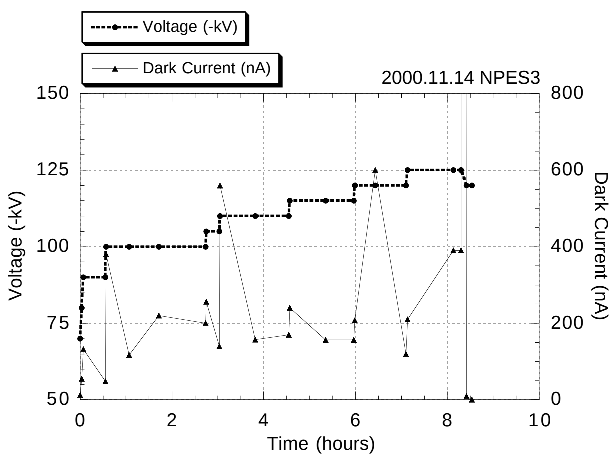

Figure 3: Reduction of the dark current by the HV Processing.

A dummy photocathode of aluminum whose flat surface was made by the diamond turning was installed at the first high voltage test. The dark current could be kept at low level of < 0.1 nA up to 138 kV and then a sudden HV breakdown occurred. For this damaged electrode, the dark current was stepped up to 140 nA even at 65 kV. To improve this situation, the HV processing method was employed by introducing 99.9999 % pure nitrogen gas into the gun chamber until the pressure become to ~ 1×10^{-6} torr [9]. In order to avoid giving the permanent damage to the electrode surface, the dark current level was kept < 1 μA during the processing. The HV was maintained at the constant value until the dark current was decreased. This process is shown in Figure 3. As a result, following a sudden HV breakdown at 125 kV the dark current dropped to a level of < 0.1 nA.

The dark current test in UHV condition at higher voltage was again continued and the extremely low dark current of < 0.1 nA was kept up to 200 kV. The gas pressure of dry nitrogen in the insulation tank was 3.6 atm for this experiment. Figure 4 show the increase of UHV pressure together with the increase of the bias voltage. For this clean surface, it took only 40 minutes to reach at 200 kV. At no bias voltage, the total pressure was 3.54×10^{-11} torr. The initial pressure at 200 kV was 3.80×10^{-11} torr but it dropped to 3.74×10^{-11} torr after 10 minutes. Therefore, the absolute pressure rise was less than 2.0×10^{-12} torr, which will be enough low to maintain the high quantum efficiency of the NEA photocathode.

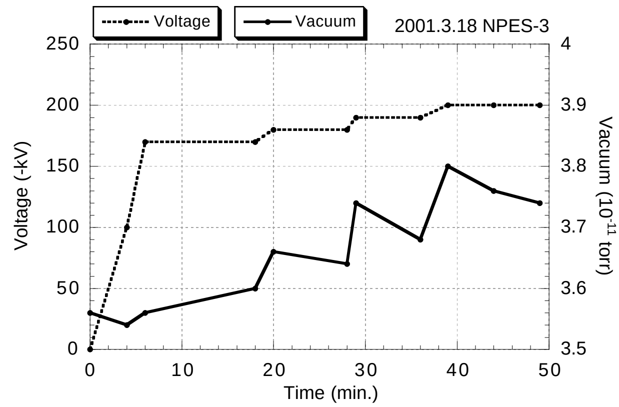

Figure 4: The increase of pressure with supplying a high voltage of 200 kV.

5 SUMMARY

The HV test of the new polarized DC-gun gave a successful result, which achieved an extremely low dark current of < 0.1 nA at a DC high voltage of 200 kV. The extraction of the 200 keV polarized electron beam from the NEA photocathode will be done soon.

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