# 200 keV POLARIZED ELECTRON SOURCE FOR LINEAR COLLIDER

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*Abstract*

A high gradient polarized electron gun with GaAs-type photocathode is indispensable to produce the high intensity and low emittance polarized beam that is required by a future $e^+$-$e^-$ linear collider. For this purpose, a 200keV electron gun was designed and has been constructed. It is capable to prepare the high quantum efficiency (QE) photocathode using atomic hydrogen cleaning method and to transfer this photocathode to the gun without breaking ultra-high vacuum. The 200keV electron beam was already extracted with dark current less than 1nA. Details of this apparatus and results of experiments are presented in this paper.

## 1 INTRODUCTION

The 200 keV polarized electron gun has been constructed for generation of high-intensity (>3A peak current), low emittance (≤10π mm mrad at the gun exit), and multi-bunch structure (~700ps bunch width, 2.8ns separation) beam required by Japan Linear Collider [1].

The polarized electrons are produced by photo-emission from a GaAs-type semiconductor with Negative Electron Affinity (NEA) surface. We develop the superlattice photocathode with heavily p-doped surface, since it has various advantages to have high electron spin polarization (ESP), high QE, and high resistance against the surface-charge-limit phenomenon. Most recently, The GaAs-GaAsP strained-superlattice photocathode has been developed [2]. It was already demonstrated by a 70keV gun that the highly ESP (~80%), 2-bunch (1ns width and 2.8ns separation) beam can be produced by this superlattice photocathode, where the peak current of 1.6A is limited by space charge limit of the gun [3],[4].

It is known that field emission dark currents between accelerating electrodes degrade the NEA surface through the following processes. The dark currents from cathode-electrode increase the vacuum pressure through the stimulated desorption of gases from the anode. Those out-gases are ionized by the electron beam itself extracted from the photocathode, and positive-ions back-bombard and degrade the NEA surface.

Therefore the reduction of the dark current is essential for a successful operation of the high gradient gun. In this respect, we employed two procedures for this gun.

i) In order to prevent the Cs accumulation on electrodes, a load-lock system is employed, which transfers the photocathode between the activation and the gun chamber. ii) The selection of the material and the fabrication procedure of electrodes are made carefully based on our fundamental study of dark current [5].

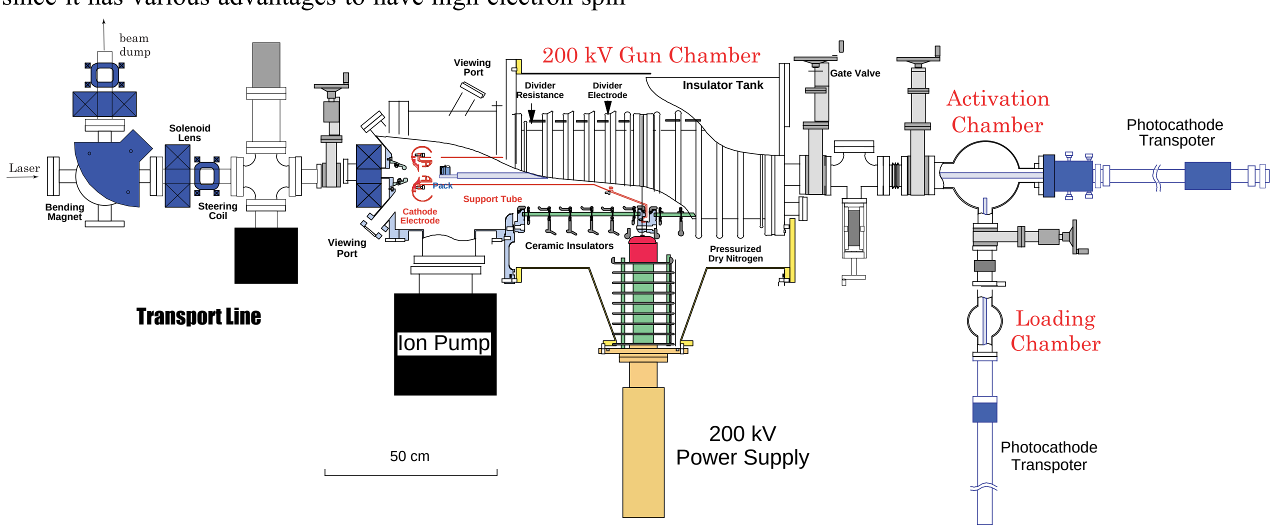


Figure 1:A schematic view of the 200keV polarized electron source.

## 2 200 KEV POLARIZED ELECTRON SOURCE

### *2.1 Load Lock System*

The mechanical structure of the 200keV gun is shown in Figure 1. This system consists of the following three sections which are isolated by gate valves. Photocathodes are transferred between the chambers by the magnetic manipulators.

1) Loading chamber: introduce photocathodes from atmosphere to ultra-high vacuum (UHV) and make Atomic Hydrogen Cleaning (AHC).
2) Activation chamber: make the RF induction heating, NEA activation by deposition of Cesium and Oxygen.
3) Gun chamber: extract the beam at DC 200kV.

The structures of 1), 2) chambers are shown in Fig. 2.

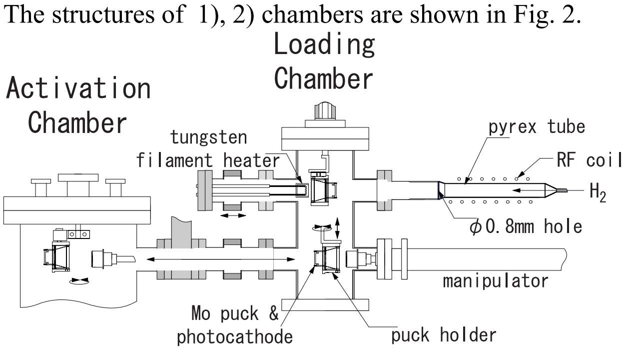


Figure 2: A schematic view of the preparation system.

### *2.2 200 kV Gun*

As shown in figure 1, high voltage is applied at the centre of two ceramic insulator-columns to which the cathode support tube is connected. Each ceramic is divided into five segments with shield rings and is jointed by 500 MΩ divider resistors for the uniform high voltage distribution. In order to suppress the leakage currents along the ceramic surface and corona discharge, the insulation gas tank is filled up dry nitrogen with pressure above 3.6atm.

The photocathode diameter and cathode-anode gap distance are chosen as Ø18mm and 35mm, using the design simulation of EGUN code, so that the maximum space charge limit become ~30A with full size laser illumination at 200kV. The field gradient on the surface of the photocathode is estimated as 3.0MV/m, and maximum field gradient on the cathode electrode as 7.8MV/m, using the simulation code of POISSON [6].

To reduce the dark current, the electrodes is made of the re-melted stainless-steel block named Clean-Z, and the surface is polished by electro-chemical buffing method and the subsequent rinsing with ultra-pure water is employed to remove the dust effectively from the surface. The microscopic field enhancement factor after such treatments was estimated as β ~40 by the separate measurement using the test electrode [5].

At the gun chamber, UHV is also indispensable for the long photocathode lifetime. The 360l/s ion-pump and 850l/s non-evaporable getter pump are used to obtain UHV. After the vacuum bake out of the chamber at temperature of 200ºC for 100 hours, the gun chamber pressure fell down below $10^{-8}$Pa. A typical vacuum pressure was $3\cdot10^{-9}$Pa measured by an extractor gage.

The insulation gas tank and high voltage power supply unit are isolated from ground, so that the field emission dark current from electrodes can be measured separately from the discharge current, which is occurred between high voltage elements and insulation gas tank.

### *2.3 Atomic Hydrogen Cleaning*

The GaAs-GaAsP strained-superlattice photocathode developed by us has many advantages, such as high ESP, high QE and high resistance against surface-charge-limit effect. However, it seems problematic to clean up the surface of such a thin layer by the standard heat cleaning at temperature around ~600ºC without degradation of its delicate structure.

In order to solve this problem, the AHC method is employed, which is capable to remove oxides and carbides without stripping a significant amount of GaAs from the surface layer. Atomic hydrogen was produced at the RF dissociation tube made of Pyrex glass which is surrounded by a helical resonator. This apparatus is the same that has been used at TJNAF in principle [7].

## 3 RESULT

The high voltage performance was tested with a bulk GaAs photocathode. The dark current began to appear when the bias voltage was applied above 120kV, as shown in Figure 3. To improve this situation, the high voltage processing was done by introducing pure nitrogen gas into the gun chamber up to $\leq 1\cdot10^{-4}$Pa. Then, the dark current was greatly suppressed, and finally we have succeeded in applying 200kV to the gun with low dark current less than 1nA.

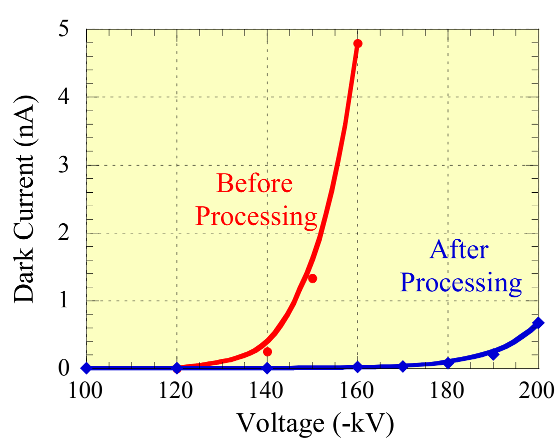


Figure 3. Dark current reduction by the high voltage processing using the pure nitrogen gas

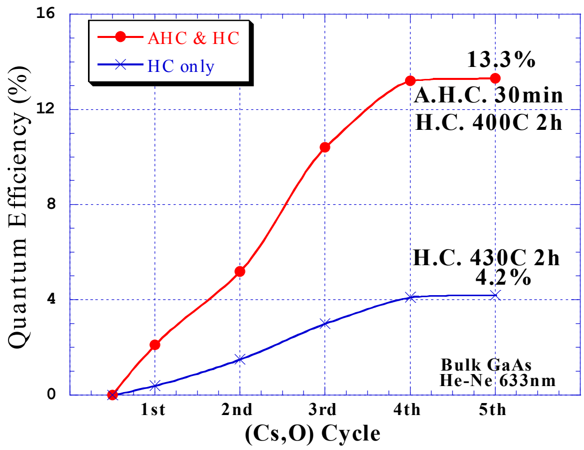


Figure 4: Maximum quantum efficiency vs. (Cs, $O_2$) deposition cycles obtained by a bulk GaAs photocathode.

We operated the atomic hydrogen source under following conditions; hydrogen gas into the dissociation tube with a pressure of ~3Pa, RF frequency of 100~110 MHz, vacuum pressure of ~$10^{-3}$Pa at the loading chamber, the photocathode temperature of ~400ºC during the cleaning.

After AHC, the vacuum pressure of the loading chamber fell down below $10^{-6}$ Pa after ~30 minutes evacuation by a 100l/s ion-pump, and then the photocathode was transferred to activation chamber.

A typical NEA activation of a bulk GaAs photocathode prepared after AHC is shown in Fig. 4. The QE of the photocathode was measured using He-Ne laser, and it was greatly improved after AHC compared to the standard heating method only. This QE value of ~14% is consistent with the result of TJNAF group [7].

We applied this method also to the GaAs-GaAsP strained-superlattice photocathode. The preliminary results of QE for this photocathode are shown in Fig. 5.

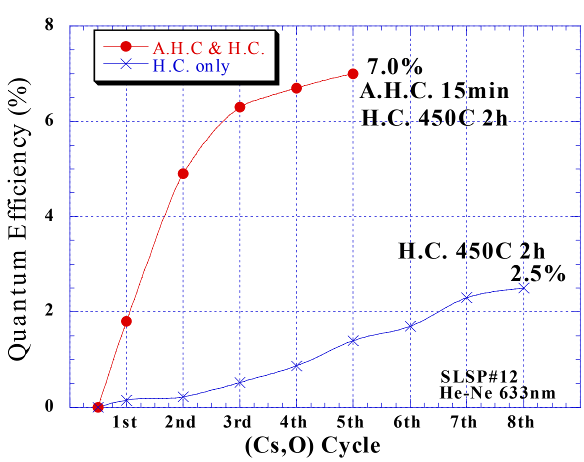


Figure 5. Maximum quantum efficiency vs. (Cs, $O_2$) deposition cycle obtained by the GaAs-GaAsP strained-superlattice photocathode.

The high QE (7.0% at 633nm and 1.2% at 780nm) was obtained for this superlattice photocathode by a combination of 15 minutes AHC and 2 hours heat-cleaning at ~450ºC. The QE was enhanced by a factor of 3 compared with that of heat-cleaning only. It was also observed that the decrease of photoluminous intensity from the superlattice layer was hardly observed for the cathode after AHC. This result suggests that the delicate superlattice structure can be preserved during AHC process with the 450ºC heat cleaning.

For the lifetime measurement, the photocathode after NEA activation was installed at the centre of the cathode electrode and illuminated by He-Ne laser. The laser spot diameter at the photocahtode was Ø1.2mm. The electron beam was transferred to Faraday Cup (FC) mounted at the end of the beam transport line and the transmission loss of the beam from the gun to FC was tuned out less than 2%.

The lifetime for the bulk GaAs photocathode was measured by extracting the continuous beam of ~100nA at -200kV. Although the dark current has been well suppressed below 1nA, the preliminary lifetime was only ~30 hours. This is probably due to the harmful residual gasses remained at the gun chamber. In fact, the partial pressure of the water was ~$1\cdot10^{-9}$Pa measured by a residual gas analyser and it is considered too high from our experience of the 70keV gun operation. Now, the UHV system has been checked and reconstructed to find the solution of this problem.

## 4 CONCLUSION

We have constructed a 200keV polarized electron gun and could already produce the 200keV beam. The load-lock system worked well and the high QE of photocahtode was obtained. Now, we have been trying to improve the photocathode lifetime. As the next experiments by this gun, the production of high intensity multi-bunch polarized beam for linear colliders and measurement of beam emittance at the source are scheduled.

## 5 REFERENCES

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