ULTRA-HIGH-VACUUM PROBLEM FOR 200 KEV POLARIZED ELECTRON GUN WITH NEA-GaAs PHOTOCATHODE

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Abstract

A high gradient electron gun with an NEA-GaAs-type photocathode is indispensable to produce the high intensity (polarized) electron beam for a future e^+-e^- linear collider (LC) and the low emittance CW beam for energy recovery linac (ERL) projects. Motivated by these needs, a 200keV (polarized) electron gun has been constructed at Nagoya Univ. The source emittance measurement system is also constructed and preliminary results are obtained. However, the lifetime of the NEA surface is not yet sufficiently long, and this problem is discussed with the efforts for improvement.

INTRODUCTION

A proto-type of 200keV polarized electron gun has been constructed for applications to the LC and ERL projects. As well known, the warm-technology-based LC requires high-intensity (>5A peak current), multi-bunch structure (~500ps bunch width, 1.4ns separation) beam with low emittance (<10π·mm·mrad) at gun exit[1]. The ERL requires large average current (~100mA) beam with the lowest emittance (<0.5π·mm·mrad)[2].

In such applications, the NEA (Negative Electron Affinity) surface makes an indispensable role to extract electrons in conduction band minimum into vacuum. It assures high polarization (P≅90%), high quantum efficiency (QE≥0.5%) [3] and lowest initial emittance (ε≅0.1 π·mm·mrad) [4] of the extracted beam.

On the contrary, there is a serious NEA lifetime problem. The NEA surface is realized by a mono-layer of electric-dipole-moment of Ga(-)–Cs(+) formed by the Cs deposition to the GaAs surface. Thus this surface state is extremely delicate against environment. In fact, the NEA surface is easily degraded by (a) desorption of residual gas molecules, (b) desorption of additional gas molecules created by the dark currents from high voltage electrode, and (c) NEA surface back-bombardment of the positive ions produced by the beam itself. In order to reduce these effects, high quality ultra-high-vacuum (UHV) is required in the vicinity of NEA surface.

The dark current induced by field emission from the cathode electrode surface is enhanced by secondary electron and ion productions. It must be also suppressed below 10nA level to maintain the UHV condition.

For keeping the lowest initial source emittance, on the other side, the higher gradient field at the NEA surface is required to prevent the beam divergence due to the space charge effect. It means that the NEA lifetime problem becomes more and more serious, if we require the higher field gradient to realize the lower source emittance.

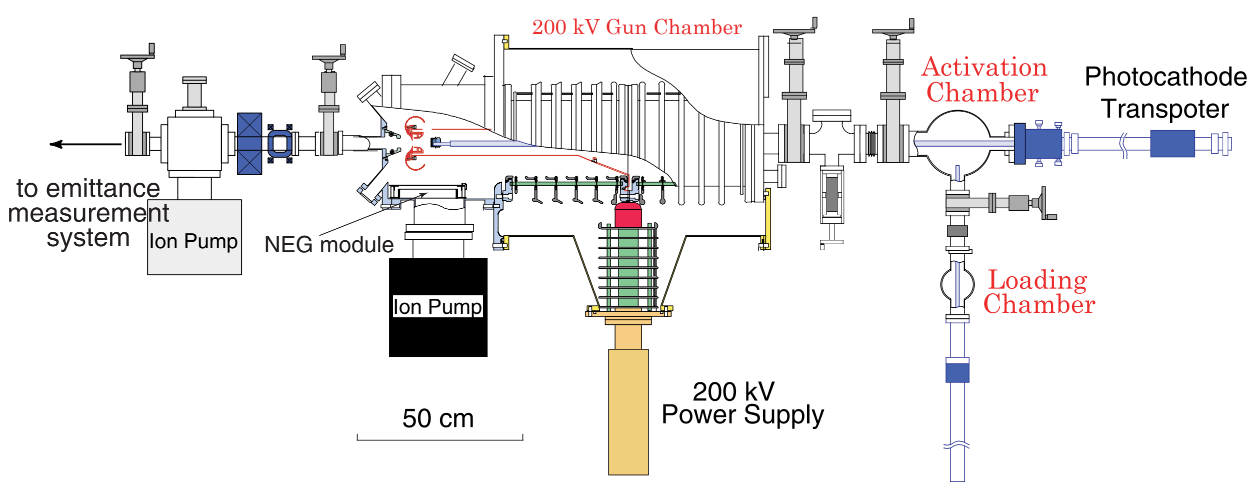

Figure 1: A schematic view of the 200keV polarized electron source.

DESIGN OF 200 KEV GUN

The mechanical structure of the 200keV gun is shown in Fig. 1. The gun consists of three sections which are isolated by gate valves. The photocathode is transferred between these chambers by two magnetic manipulators. The preparation chamber introduces the photocathode from atmosphere to UHV, and makes the surface cleaning by atomic hydrogen gas. After the photocathode is further cleaned by the RF heating, the NEA activation is made by deposition of Cs and O_2 or NF_3 in the activation chamber.

The load-lock system worked well and the gun could already produce the highly polarized electrons from a thin layer of GaAs-GaAsP strained superlattice structure [3]. The high QE (7.0%@633nm and 1.2%@780nm) was also achieved using the 15minutes atomic-hydrogen cleaning at <400ºC and the 2 hours heat cleaning at ~450ºC).

High voltage of 200kV is applied to a centre of double ceramic insulators, to which the cathode supporting tube is also fixed. In order to suppress the leakage currents along the ceramic surface and the corona discharge to the ground, the dry nitrogen is fulfilled into the insulation gas tank with pressure above 3.6atm.

ULTRA-HIGH-VACUUM

Pumping System

The high quality UHV is indispensable for the long lifetime of NEA surface. The original pumping system of the gun chamber was designed to have a 360l/s ion pump and an 850l/s non-evaporable getter (NEG) pump. The total pressure and partial pressures of residual gas were monitored by an extractor gage (IE514; Leybolt) and a residual gas analyser (TH200; Leybold), respectively. After bake-out of the gun chamber at 200ºC for 100hours, the vacuum pressure fell down to 3.2×10^{-9} Pa and the partial pressure of H_2O became to 1.1×10^{-10} Pa. However, the QE lifetime for a photocathode was rather short of ~40hours, in either case of a 200keV CW beam operation with ~100nA, or an intermittent QE measurement by a 5keV beam. The latter is so called as dark lifetime measurement.

These data suggested that the QE lifetime is limited by degradation of the NEA surface by adsorption effect of harmful residual gases. In order to achieve the extra-high-vacuum $<10^{-10}$ Pa by relaxing this effect, the following improvement were introduced.

- All valves used in the gun chamber were replaced from viton-seal to metal-seal for proof against the bake-out at higher temperature (≤200ºC).
- The additional NEG pumping modules were installed to reinforce the pumping speed under UHV.

The total pumping speed was reinforced up to 4650l/s using eight NEG pump modules (WP950×8; Saes Getters) that were installed around a photocathode. They are fixed to a rigid frame as shown in Fig. 2. The designed activation temperature was ~450ºC with 35A supplied current for each module. The mesh of stainless-steel is used to cover inner-side of the frame for masking the NEG modules from the high voltage electrode. The NEG module system was insulated from the ground so that the emitted current from the electrode to the mesh could be monitored.

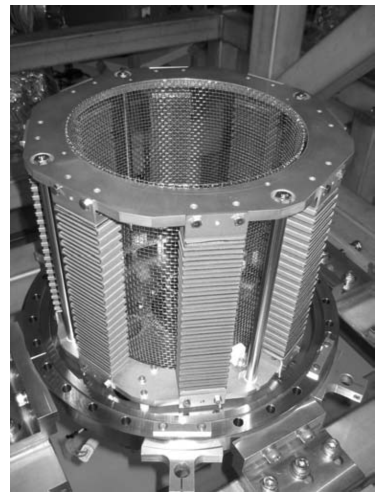

Figure 2: The NEG modules fixed to the rigid frame.

Preliminary Results of UHV

The results of preliminary UHV-test are as follows. The baking of the gun chamber with various parts was done at 200ºC for 100 hours. The heating temperature of NEG modules was as same as the baking temperature of 200ºC, due to a trivial accident of current supply circuit. It means the pumping speed of NEG modules was expected to be lower than the designed speeds.

The total pressure, wall temperature and partial pressures of H_2, CH_4, H_2O, CO/N_2, CO_2 were monitored with time as shown in Fig.3. It shows the H_2 and CH_4 were dominant components before the NEG pumps activation, and then the CH_4 component decreased while H_2 still remained.

The total pressure was improved from 3.2×10^{-9} Pa to 5.7×10^{-10} Pa, in spite of the incomplete activation of the NEG modules. The partial pressures of harmful gasses were also reduced to 2.6×10^{-11} Pa for H_2O and 5.1×10^{-11} Pa for CO_2, respectively. They are summarized in Table 1.

Table 1: Improvement of total and partial pressures of residual H_2O and CO_2 in the gun chamber

	Pressure	H_2O	CO_2
Before	3.2×10^{-9}Pa	1.1×10^{-10}Pa	2.3×10^{-10}Pa
After	5.7×10^{-10}Pa	2.6×10^{-11}Pa	5.1×10^{-11}Pa

Preliminary Results of Lifetime

A preliminary dark-lifetime measurement is done using a He-Ne laser (λ=633nm) at a bias-voltage of -5kV under the above UHV condition. The QE decrease with time is shown in Fig. 3, together with previous data.

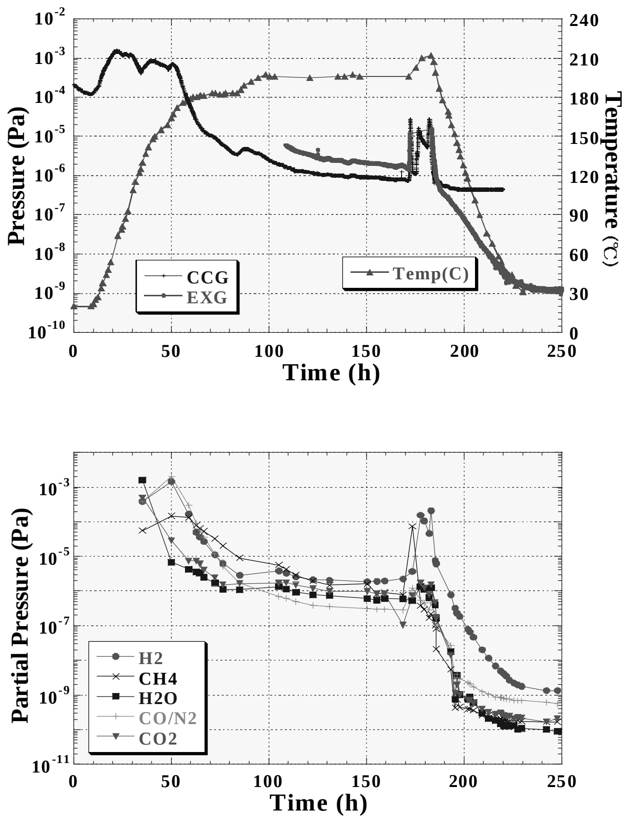

Figure 3: The total pressure, the wall temperature and the partial pressures of H_2, CH_4, H_2O, CO/N_2, CO_2 were monitored during the baking of the gun chamber.

The dark-lifetime is improved from 40 to 150 hours, and it is reconfirmed that the reduction of harmful residual gasses (in particular, H_2O and CO_2) is so important to preserve the NEA surface state.

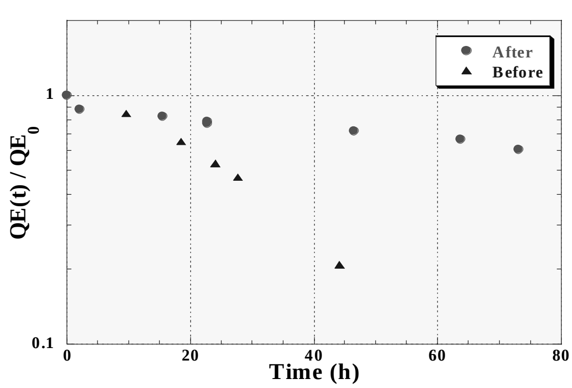

Figure 4: Preliminary result of dark-lifetime measurement.

EMITTANCE MEASUREMENT

An emittance measurement system employing a high-precision pepper pot technique has been introduced to our gun system. It was developed at KEK for the emittance measurement of a thermionic cathode gun [5] and now is modified for the NEA-GaAs cathode gun.

As shown in Fig. 4, the beam shot from the gun is masked by pepper pot placed at a distance ~1m from the photocathode, and the beamlets that pass by the mask drift about 56mm and hit a screen of scintillator film. The signal light (λ=375nm) passes through an IR-cut-filter to eliminate the background due to laser light (λ=780nm for Ti:Sapphire, λ=633nm for He-Ne). Small luminous spots on the screen are magnified by a telescope, amplified by an image-intensifier and finally converted into the electrical images by a CCD camera. The source emittance less than 0.7π·mm·mrad can be measured by this system.

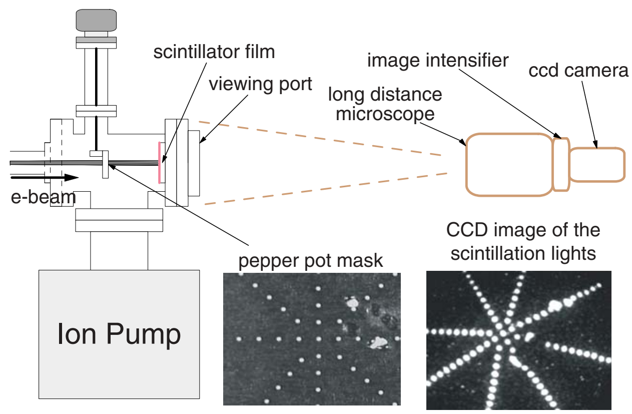

Figure 5: Pepper pot type emittance measurement system.

Preliminary results of the emittance measurement are obtained using a test beam from the 200keV gun.

SUMMARY

We have tried to improve the lifetime of NEA-GaAs photocathode by reinforcing the pumping power and also making the high temperature baking for the gun chamber. The dark-lifetime of preliminary test shows 150hours and the better lifetime will be obtained by increasing the NEG activation temperature from 200ºC to 450ºC. The precise measurement of source emittance becomes also possible.

Studies to improve the dark-lifetime and increase the field gradient by new electrode with Mo-cathode and Ti-anode are in progress [6]. Other experiments using this gun system are also scheduled to produce the nanosecond multi-bunch polarized beam for the LC project and the low emittance CW beam for the ERL project.

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