A CHARGE LIFETIME STUDY OF NEA GaAs CATHODE BY ION BACK-BOMBARDMENT*

M. Kuriki#, KEK, Ibaraki, Japan and AdSM, Hiroshima University, Japan
K. Miyoshi, L. Guo, AdSM, Hiroshima University, Japan
H. Iijima, RISE, Waseda University, Japan

Abstract

GaAs photo-cathode with NEA (Negative Electron Affinity) surface is a unique device and should have an important role in advanced accelerators such as International Linear Collider and light sources based on Energy Recovery Linacs. With the NEA surface made by artificial treatment, an ultra-low emittance and polarized electron beam can be extracted by photo-electron effect with laser photon whose energy corresponds to the band gap. The surface is sensitive to residual gas adsorption and ion impact ionized with the electron beam. The latter effect is called as Ion Back-Bombardment (IBB) and currently limits the effective operational lifetime of the cathode in high average current applications. In Hiroshima University, IBB has been studied and the result showed that IBB can be characterized by an impact coefficient for ion density per second. On the other hand, effects of gas adsorption and IBB were not clearly separated experimentally in our measurements. To improve our measurement, the system was modified to control electron and ion orbits. An electron beam collector is placed to suppress vacuum pressure evolution during the measurement. Expected performance of our new test bench is presented.

INTRODUCTION

We have studied operational lifetime of GaAs photo-cathode with NEA surface electron source for International Linear Collider [1] (ILC) and Energy Recovery Linac [2] (ERL) in Hiroshima University. The advantages of the cathode are able to generate ultra-low emittance and polarized electron beams with circularly polarized laser. The operational lifetime [3] is limited and it is the biggest issue especially for high average current applications such as light source based on ERL. The mechanism of the short lifetime have been identified by past studies[4-6] as gas adsorption, thermal desorption, and IBB. The thermal desorption is dissociation of Cs-O layer and becomes significant only when the cathode temperature is more than 340K [5]. It can be suppressed by controlling the temperature. Gas adsorption is de-activation of NEA surface by chemically active residual gases. Effect of the gas adsorption was understood quantitatively well [6] and is suppressed by controlling partial pressure of high impact gases such as O_2, H_2O, and CO_2. Quantitative formalization of IBB is the biggest issue to solve the lifetime problem on NEA GaAs cathode.

We have performed the cathode activation experiments with photocathode test bench [7]. We activate GaAs cathode with cesium (Cs) and oxygen (O_2) in extremely low vacuum pressure (typically 1.0E-9Pa) and perform the electron emission measurement. To study IBB, evolution of quantum efficiency of the cathode was measured in high electron beam density. The quantum efficiency should be decreased regarding to the extracted charge density by IBB, but it was also affected by the gas adsorption effect. These two effects have to be clearly separated to study IBB quantitatively; the separation is currently not enough. During measurements, the vacuum pressure was changed by a large amount of out gas from the chamber wall by the electron beam impact. Another issue is ambiguity on the ion orbit. In our current configuration, only a fraction of the generated ions go back to the cathode surface and number of ions cannot be controlled.

In this study, the cathode test bench is modified to solve these problems to realize quantitative understanding on IBB. Electron and ion orbits in the modified configuration are simulated and expected performance is shown.

PHOTO CATHODE TEST BENCH

NEA-GaAs photocathode test bench [7] in Hiroshima University consists from two vacuum chambers isolated with a gate valve. One is preparation chamber where the cathode is prepared and activated. Another is experimental chamber where the beam emission experiment is carried out. NEA surface is made by deposition of Cs and O2 on Yo-Yo method in preparation chamber. The cathode is then transferred to the experimental chamber by a transfer rod in vacuum. Vacuum pressures of these chambers are kept in extreme high vacuum region; typical pressures are 9.0×10^{-10} Pa for the experimental chamber and 4.0×10^{-9} Pa for the preparation chamber.

Figure 1 shows cross section of the experimental chamber. An L shape component in the centre of chamber is cathode holder where NEA-GaAs photocathode is mounted. A He-Ne laser with wavelength of 633nm is employed for the photo-electron emission and is introduced from a viewport.

*Work supported by Mext Quantum Beam Technology Program, KEK Promotion of collaborative research programs in university.
mkuriki@hiroshima-u.ac.jp

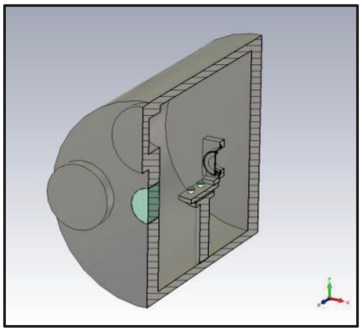

Figure 1: A cross section of the experimental chamber. The component in the centre of chamber is cathode holder.

To study IBB effect, we measure QE evolution in two experimental modes. One is “dark mode” where the emission current density is negligibly small, 10nA/mm2 or less. In this mode, QE evolution is dominated by residual gas adsorption. QE is decreased exponentially regarding to time. Another mode is “beam mode” where the emission density is large, 10μA/mm^2 or more. In this mode, QE evolution is influenced by both the effects, i.e. gas adsorption and IBB. By taking QE evolution in these two modes and removing gas adsorption effect, QE evolution by IBB is extracted.

However, if vacuum pressure was largely changed during the measurement, the analysis would be difficult and the accuracy would be limited. Fig.2 shows vacuum pressure and beam current evolutions in a beam mode measurement. A large change on the vacuum pressure was observed. Since the vacuum pressure evolution was in a same trend as that of the beam current, the reason of this large change is gas desorption from the chamber wall by the electron beam.

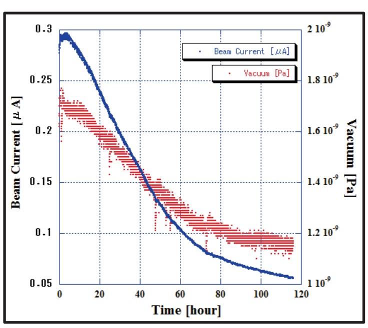

Figure 2: Beam current decay and vacuum level change.

Figure 3 shows a simulation result of beam tracking in the chamber. Colored lines are equipotential lines. The cathode was biased at -100V and chamber was set at ground. The static electric field was calculated with CST STUDIO [8] and the particle tracking was performed with GPT [9].

1μA electron beam was generated in 1mm radius on the cathode. It is clearly shown that the beam hits the vacuum chamber wall. To prevent vacuum pressure evolution during the experiment, an electron collector is placed. The collector is implemented with a heater, so that the collector can be well baked with high temperature to suppress the gas desorption by electron beam impact.

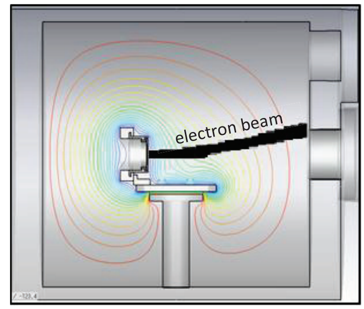

Figure 3: A cross section of electric potential and orbit of electron beam in the experimental chamber.

IBB SWITCHING

Collector electrode to prevent outgas by electron beam was designed as follows. In addition, we designed electrodes controlling electric field to switch IBB, i.e. in a bias condition, positive ions hit the cathode (IBB on), but in another condition, it does not (IBB off). For these purpose, we put several electrodes in near of the cathode holder as shown in fig.4. Two side and one top electrodes are set to control the ion orbit and one electrode at right end is the beam collector.

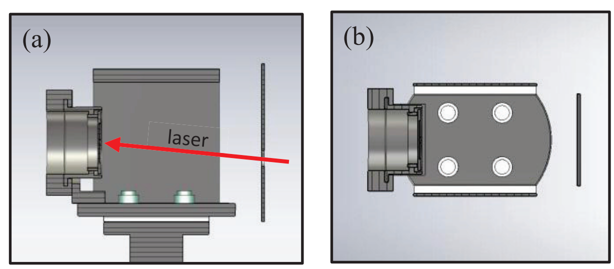

Figure 4: The photocathode test bench with electrodes. (a) shows vertical cross section and (b) shows horizontal section.

Figure 5 shows simulation results of electric field around cathode in photocathode test bench with these electrodes. In IBB on condition (fig. 5(a)), symmetric electric field is formed. In IBB off condition (fig. 5(b)), the field is asymmetric and ions generated by the electron beam do not go back to the cathode.

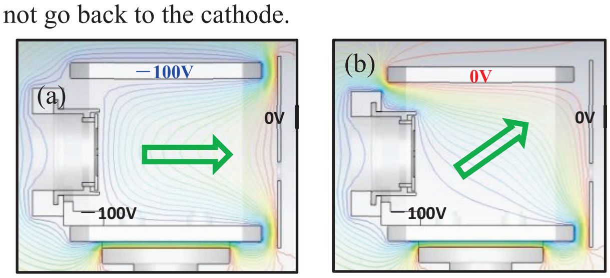

Figure 5: A cross section of electric potential formed by electrodes. (a) shows result in promoting IBB, (b) shows result in disturbing IBB.

Figure 6 shows simulation results of electron and ion orbits, blue points are electron emitted from photocathode and red points are H_2^+ ion generated at a distance of 10mm from photocathode on electron beam orbit. From these results, it was confirmed that IBB can be controlled by switching the bias condition.

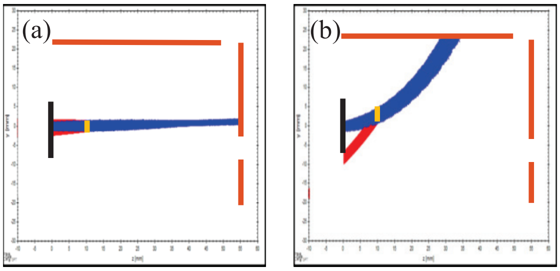

Figure 6: Simulation result of electron (blue) and ion (red) orbits in vertical plane. (a) shows result in promoting IBB. (b) shows result in disturbing IBB.

Ion density (N) in IBB on and off conditions were estimated as

$$N = \int_{z_1}^{z_2} \frac{I}{\varepsilon} \sigma n_R R dz, . \qquad (1)$$

where I is electron beam current, σ is ionization cross section, n_R is gas density, R is ion collision rate on cathode estimated by the simulation. Table1 shows calculation results. In the calculation, the beam current was 1μA, all ions are H_2^+, n_R was $2.2\times10^{10}\text{m}^{-3}$ corresponding 1.0×10^{-9} Pa pressure in room temperature.

Table 1: Ion Density on Cathode with IBB On and Off Conditions

Simulation condition	Ion density $(1/(s \cdot A \cdot m^2 \cdot Pa))$
Original test bench	3.6×10^{23}
Disturbing IBB	0
Promoting IBB	5.0×10^{23}

The results clearly show that IBB effects could be controlled by the bias condition.

Later, we found there is bias in the collision distribution on photocathode. Fig.7 shows the condition of voltage applied electrodes and distribution of colliding ions. This problem will make the study of IBB effect be difficult.

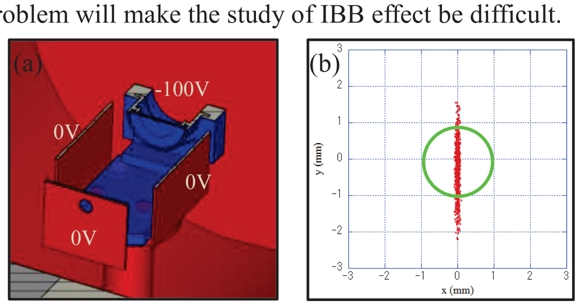

Figure 7: The condition of voltage applied electrodes (a) and distribution of colliding ions (b). Green ring in right figure is electron generation area.

To solve this bias, we changed voltage applied with side electrodes. In fig.8, the distribution spread in horizontal direction with applying voltage to side electrodes and found to improve bias distribution. We have been optimizing the experimental conditions currently.

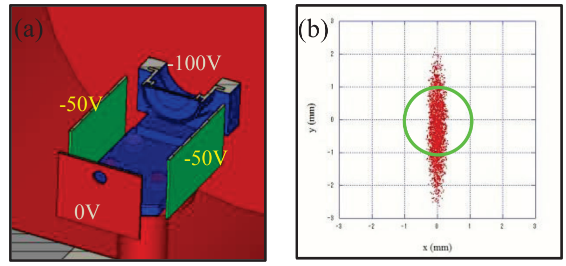

Figure 8: The new condition of voltage applied electrodes (a) and distribution of colliding ions (b). Green ring in right figure is electron generation area.

SUMMARY AND FUTURE PLAN

We simulated electric field with CST STUDIO and electron and ion orbit with GPT in photocathode test bench. We designed electrodes to form experiment environment to study IBB effectively. In simulation results, the efficiency of electrodes was confirmed. We have been optimizing the experimental conditions currently.

After this, we will examine pattern of applying voltage to electrode and actually carry out experiment using photocathode test bench with designed electrodes.

ACKNOWLEDGMENT

This work is partly supported by the Quantum beam Project by the Ministry of Education, Culture, Sports, Science and Technology, entitled High Brightness Photon Beam by Laser-Compton Scattering and Cooperative supporting program for Researches an Educations in Unversity by KEK (High Energy Accelerator Research Organization).

REFERENCES

[1] ILC Reference Design Report.
[2] KEK Report No.2007-7/JAEA Research 2008-032 (2008), edited by R.Hajima, N.Nakamura, S.Sakanaka, and Y. Kobayashi.
[3] M. Yamamoto, Proceedings of the 1st Annual Meeting of Particle Accelerator Society of Japan (2004).
[4] G. Lei, et al., Proc. of Annual Meeting of Particle Accelerator Society of Japan (2012).
[5] C. Shonaka, et al., Proc. of Annual Meeting of Particle Accelerator Society of Japan (2009).
[6] M. Kuriki et al., Proc. of this conference (2013) MOPFI012.
[7] H. Iijima, et al., Proc. of Annual Meeting of Particle Accelerator Society of Japan(2012).
[8] http://www.aetjapan.com/software.php?CST_STUDIIO_SUITE.
[9] http://www.aetjapan.com/software.php?Accelerators_Desig =GPT.