MEASUREMENT OF ADSORPTION RATES OF RESIDUAL GASES FOR NEA-GAAS SURFACE*

M. Kuriki#, H. Iijima[a)], K. Miyoshi, K. Uchida,
AdSM/Hiroshima University, Higashi-Hiroshima, Japan, [a)]RISE/Waseda University, Japan

Abstract

NEA-GaAs photocathode has an important role in linac based future accelerators such as linear colliders, ERL light source, etc. Because it has high quantum efficiency of photo-electron effect and can be driven by visible and near IR light, it is feasible for high current electron beam generation. Polarized electron beam up to 90% is obtained by employing super-lattice structure. Extremely low emittance beam is expected because the electron beam emitted from NEA (Negative Electron Affinity) surface has less excess energy. Although these remarkable features, a shot lifetime is the biggest issue from the accelerator operational view point. Physical mechanisms limiting the operational lifetime had been identified as ion-back-bombardment, thermal desorption and residual gas adsorption. We have studied the quantum efficiency degradation by means of residual gas adsorption rates by using CO, N_2, CO_2 and O_2-sample gases. We found that O_2 has the biggest effect on the quantum efficiency among the sample gases. The degradation coefficient of O_2 is 13 times larger than that of CO_2, CO and N_2 had almost no effect. According to these measurements, we have to keep the partial pressure of O_2 and CO_2 extremely low for enough operational lifetime of GaAs photo-cathode.

INTRODUCTION

Next generation light source such as energy recovery linac or free electron laser aimed to high brightness need a high quality electron source that is able to make a high average current and very low emittance. A GaAs photocathode with Negative Electron Affinity (NEA) surface with Cs and Oxygen (NEA-GaAs) is a candidate because it has a high quantum efficiency (QE) and generates an extremely low emittance beam. NEA-GaAs is also able to make highly polarized electron beam up to 90%[1], therefore, it is employed for International Liner Collider (ILC) [2] which is an electron-positron collider. NEA GaAs cathode is also applicable for various applications. SPLEEM (Spin Polarized Low Energy Electron Microscope) and DTEM (Dynamic Transmission Electron Microscope) employing NEA GaAs cathode as the electron emitter are studied [3].

Although NEA-GaAs have these excellent features, its operational lifetime is too short for practical use. Three processes that degrade NEA-surface have been identified[4]. One is Ion Back Bombardment that residual gas molecules ionized by the electron beam go back to the cathode and damage the NEA surface. Second is thermal desorption of Cs/O form NEA surface which becomes significant only at temperature more than 370K. Third is residual gas adsorption on NEA-surface.

Effects of the residual gases for the cathode lifetime were reported as follows. T.Wada et al. reported that CO_2 degraded QE, but CO did not [5]. N.Chanlek reported that CO, H_2O, O_2 and CO degraded QE, but hydrogen, nitrogen and methane did not[6]. D. Durek et al. demonstrated that the lifetime was inversely proportional to partial pressure of water vapour [7]. According to our past studies, CO and CO_2 were adsorpted on the degrade surface[8].

In this article, adsorption rate of CO, CO_2, O_2, N_2 sample gas were measured and effects on QE of NEA GaAs were extracted quantitatively.

EXPERIMENTS AND RESULTS

The experiment was performed at Hiroshima University by using of a cathode test bench consisting of stainless steel chambers equipped with a 160 l/s ion pump and a 310 l/s non-evaporable getter pump. Vacuum chamber cross sectional view is shown in Fig. 1. Base pressure was about 1e-8 ~ 6e-9 Pa during the experiments. The QMS(M101QA-TDM-W, ANELVA),which is able to measure the mass-to-charge ratio (m/z) up to 100, is placed to analyse residual gas components. Sample gases were introduced through a variable leak valve to the chamber.

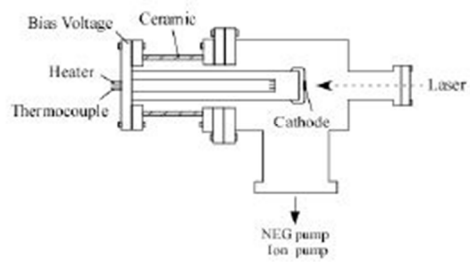

Figure 1: A cross-sectional view of vacuum chamber[4].

The p-type, Zn-doped bulk GaAs(100) was used as a cathode sample. The sample was treated only with the heat cleaning process typically at 620 deg.C without any chemical treatments. 8 % QE for 633nm photon was routinely obtained after NEA activation. The GaAs sample was soldered by indium onto a molybdenum block. A cartridge heater was mounted in backside of the block for the heat cleaning. NEA activation was performed by yo-yo method, alternate deposition of Cs and oxygen on GaAs surface. Figure 2 shows a typical evolution of QE after NEA activation with negligibly small beam current. QE was measured with 633nm He-Ne laser. After a rapid depression, QE was exponentially degraded via a plateau

region. In this article, the lifetime is defined as time constant of the exponentially decay region. Total vacuum pressure was measured by a nude ion gauge and partial pressure was measured with Q-mass as explained later in detail.

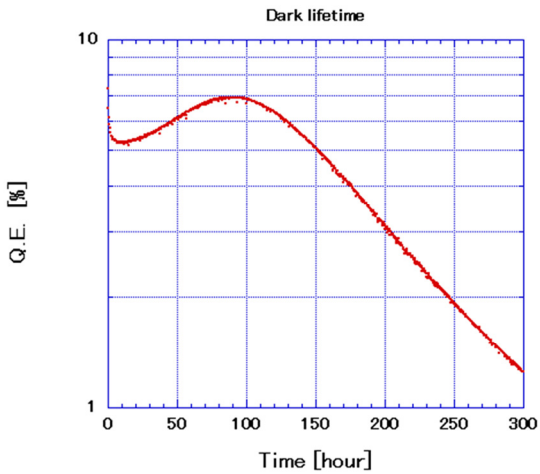

Figure 2: a non-operational typical time dependence of QE after NEA activation.

By assuming first order reaction, QE evolution by residual gas adsorption is expressed as

$$\eta(\mathrm{t}) = \eta_0 e^{-\beta t}, \quad (1)$$

where η and η_0 are QE and its initial value, β is gas adsorption rate expressed as

$$\beta = \frac{1}{\tau} = \sum \alpha_i P_i \quad , \quad (2)$$

where τ is the lifetime, α_i and P_i are degradation factor and partial pressure. The subscript means that these parameters are presented for each molecule species. In an actual measurement, degradation coefficient for the sample gas α_{sample} is evaluated as a function of the total pressure P_{all} as,

$$\beta(\mathrm{P}_{all}) = \alpha_{sample} P_{all} \, . \quad (3)$$

Figure 3 shows the measured β as a function of the total pressure for an O_2 sample gas. Each data points were obtained by exponential decay rate on each QE decay curves, but the QE decay curves were incompatible with any exponential curves when its adsorption became more than 0.05 L (Langmuir). Therefore, only data less than 0.05 L adsorption were shown. The degrade coefficient of the O_2 sample gas was 6.3e+8 /h.Pa.

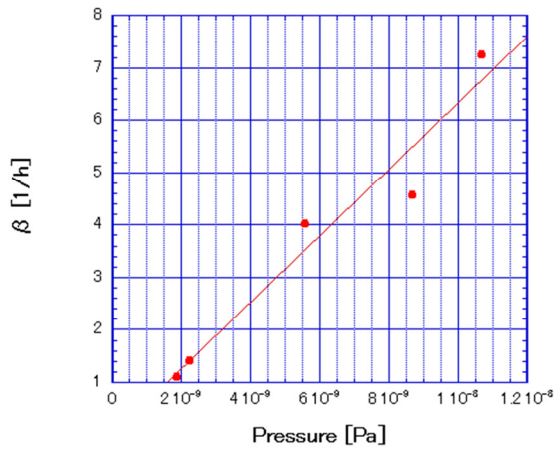

Figure 3: O_2 sample gas.

Similar measurements were made with CO, CO_2, and N_2 sample gases as follows.

Figure 4 shows the results of the CO_2 sample gas.

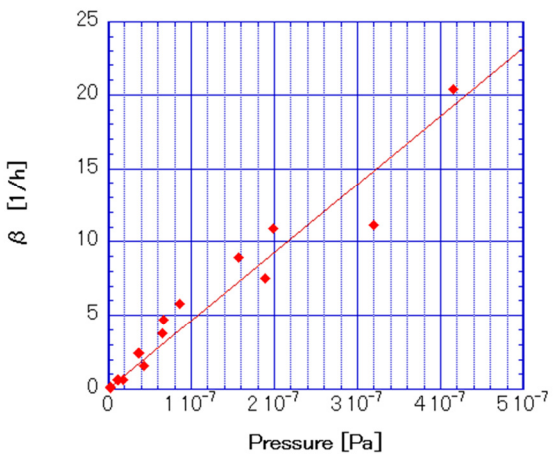

Figure 4: CO_2 sample gas.

In CO_2 case, exponential QE decay was observed up to 1.0 L and data points less than the threshold were shown. The degrade coefficient of CO_2 sample gas was 4.6e+7 /h.Pa.

Figure 5 shows the results of CO sample gas. In CO case, exponential QE decay was observed up to 10 L and data points less than the threshold were shown. The degrade coefficient of CO sample gas was 3.2e+6 /h.Pa.

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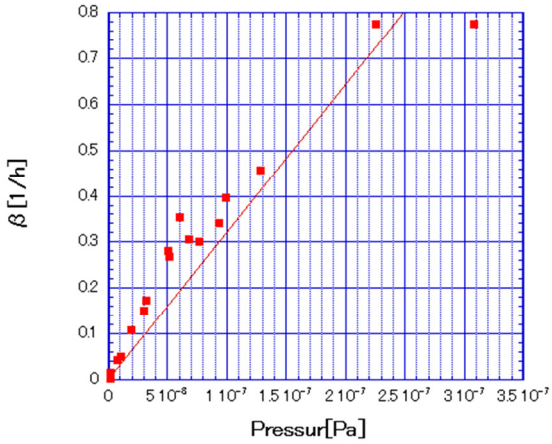

Figure 5: CO sample gas.

Figure 6 shows the result of N_2 sample gas. The degrade coefficient was 2.78e+6 /h.Pa.

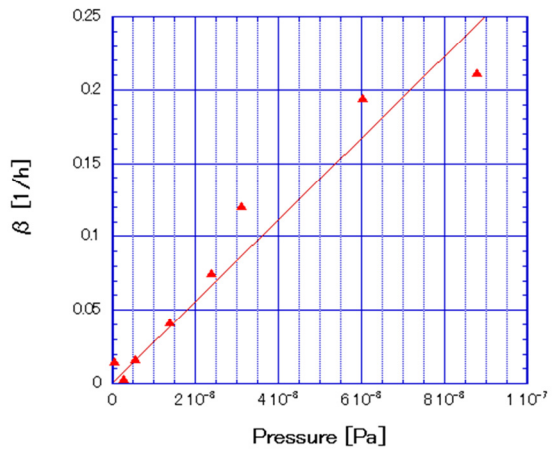

Figure 6: N_2 sample gas.

These measured α_{sample} for each sample gases are superposition of linear combinations of molecules. Fraction of molecules of each sample gases were determined from Q-mas spectra as shown in Table 1. When we calculate the fraction, we refer pattern coefficients of CO_2 from the literature [9] because we couldn't separate CO_2 and CO from mass spectra.

Degradation coefficient for each molecules α_i were determined as

$$\begin{pmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\end{pmatrix} = (A)^{-1}\begin{pmatrix}\alpha_{sample1}\\ \alpha_{sample2}\\ \alpha_{sample3}\end{pmatrix} \quad (4)$$

where A is fraction matrix determined from Q-mass spectra. In the real calculation, 4 gas components were assumed. The results were summarized in Table 2. CO and N_2 degrade coefficients were not significant and zero consistent. Degradation coefficients of O_2 and CO_2 were significant. For NEA GaAs cathode, O_2 has larger effects than that of CO_2.

Table 1: Fraction of Molecules in Sample Gases

	N_2	CO	O_2	CO_2
N_2sample	0.66	0.17	0.004	0.03
COsample	0.05	0.80	0.002	0.008
O_2sample	0.05	0.12	0.74	0.011
CO_2sample	0.15	0.19	0.012	0.54

Table 2: Calculated Degrade Doefficients

O_2	5.2e+8 ±2e+8	[/h.Pa]
CO_2	3.9e+7 ±1.3e+7	[/h.Pa]
CO	1.8e+6 ±4e+6	[/h.Pa]
N_2	-8e+5 ±9e+6	[/h.Pa]

CONCLUSION

We measured degradation coefficients of NEA GaAs photo-cathode with sample gases. The result suggested that O_2 molecule had the largest effects among the O_2, CO_2, CO and N_2 molecules. Coefficient of CO_2 was 1/13 of that of O_2. These results were consistent with the previous studies.

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