# REDUCTION OF THE FIELD EMISSION DARK CURRENT FROM COPPER SURFACE IN A HIGH GRADIENT DC FIELD

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*Abstract*

Field emission dark current is a most serious problem for a long lifetime operation of a photocathode-type RF-gun. It is especially true, if a GaAs with NEA surface shall be used as the photocathode of RF-gun to produce spin polarized electrons. To find a solution for this problem, a plan to construct an RF-gun cavity with an extremely low dark current has been started as an international collaboration of CERN / KEK-Nagoya / SLAC. As a part of this collaboration, a study was started to reduce the DC dark current from a clean copper surface. At the first step, various surface treatment methods have been examined by making test samples from Class-1 OFHC copper. Impurities on the surface were inspected by methods of SEM and AES. The surface treatments such as ozonized ultrapure water rinsing, high pressure pure water rinsing and electro-polishing have been tested. Then, at the second step, electro-polished electrodes were fabricated to measure field emission current from its surface under the DC high gradient field. Preliminary results are described in this report.

## 1 INTRODUCTION

The photoemission type RF-gun is a potential source of high current, low emittance, short bunch length electron beams. Using an RF-gun as a source of future linear collider, a bunching system can be eliminated, and the requirements for the electron damping ring are greatly loosened. Linear collider also requires polarized electrons, which are now produced by a DC-gun using a GaAs-type crystal as a photocathode. Therefore, a polarized RF-gun is the most desirable source for future linear collider. But due to the technical difficulties, the feasibility of the polarized RF gun has not yet been demonstrated.

To extract highly polarized electrons from the GaAs-type crystal, a negative electron affinity (NEA) surface is required. This surface is degraded easily, if the vacuum environment of the gun is not good. It must be kept at the vacuum level of $10^{-11}$torr and the dark current level below 10nA in the case of polarized DC-gun. [1] In the RF-gun, the extraction field at the cathode surface is as high as 100MV/m, which is about two orders of magnitude higher than that of the DC-gun. The key techniques to achieve a long lifetime of the photocathode is suppressing an RF break down and reducing the amount of dark current generated by this high field gradient. A plan to construct an RF-gun cavity with an extremely low dark currents has been started as an international collaboration of CERN / KEK-Nagoya / SLAC, to demonstrate the survivability of the NEA cathode under the high field gradient in the RF-gun. As a part of this collaboration, the study is started to reduce the DC dark current from the copper surface. This investigation is done in two steps as follows,

1) Analysis of copper surface using Scanning Electron Microscope (SEM) and Auger Electron Spectroscopy (AES), which is expected to reveal the relationship between the cleanliness and the surface treatment procedure.

2) Measurement of field emission dark current from copper surface under the high DC field gradient.

These two studies will inform us which surface treatment will be the most desirable to fabricate RF cavities.
This report shows the preliminary results of these studies.

## 2 ANALYSIS OF COPPER SURFACE

The magnitude of dark current depends on the cleanliness of the surface. Contamination, microscopic dusts on the surface, impurities of the material, have a possibility to become emission sites under the high field gradient.[2] Samples of simple shape (ϕ10x t10) were made for this analysis to compare the impurities on the copper surfaces treated by different preparation methods. Then, each sample was analyzed by AES and checked the cleanliness of its surface. The cleaning methods used in this analysis are as follows,

- Ultrapure Water Rinsing. (UWR)
- Ozonized Ultrapure water Rinsing. (OUR) [3]
- High pressure Pure water Rinsing. (HPR)
- Electro Polishing. (EP)

Table 1 shows the preparing procedures of these samples.

All the samples were machined from Class-1 OFHC (Oxygen Free High Conductivity) copper blocks with purity of 99.996%. The blocks were forged by Hot Isostatic Pressing (HIP) before the machining, in order to

reduce the micro-pores existing between the grains. These pores would be emission sites, when the machine oils were trapped in them. [4] The machining was done by diamond turning with ethanol for mirror-like finish, machine oils were not used in final turning. Surface roughness of the sample was measured to be 0.05μm. Each cleaning method was done after this machining.
The results of AES analyses are shown in Figure 1.

Table 1: Preparing procedure of the sample.

| Sample No. | Diamond turning | EP | HPR | OUR | UWR |
|---|---|---|---|---|---|
| 1 (UWR) | O | => | => | => | O |
| 2 (OUR) | O | => | => | O | O |
| 3 (HPR) | O | => | O | => | O |
| 4 (EP) | O | 5.1μm | => | => | O |

HPR : 50kg/cm$^2$, 1minutes.
OUR : 3ppm, 3 minutes. UWR : 18MΩ*cm.

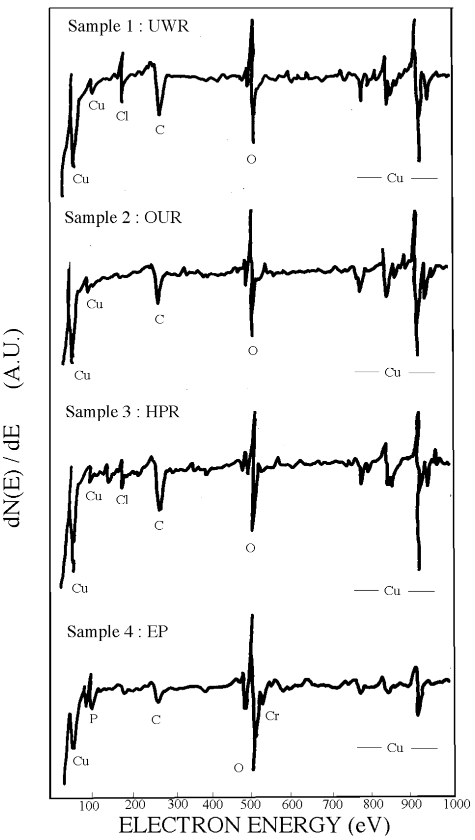


Figure 1 : Results of AES analyses for the surfaces of samples treated by different methods.

The result doesn't show so big differences, but some characteristic features of each surface treatment methods are recognized.

(1) From the analysis of sample 1, it becomes clear that the diamond turning of the copper using ethanol is less contaminated by carbon than ordinary diamond turning with machine oil.
(2) From the analysis of sample 4, it is concluded that contamination, such as C, Cl, is almost removed by the EP method. But the chemical compositions of its solution (P,Cr) are left on the surface.
(3) It is clear that the EP method removes contamination much more than the OUR method only, from the comparison of sample 2 and 4. But the increase of oxidized layer is remarkable in the EP surface.

The EP surface is very clean from the viewpoint of carbon contamination. As the first copper electrodes for the DC high gradient test, the EP method was adopted for this reason.

## 3 DARK CURRENT TEST-APPARATUS

A test apparatus was build to investigate the relationships between the surface conditions and the amounts of dark current systematically. This apparatus can supply ultra high vacuum (~10$^{-11}$Torr) and the high DC field gradient, to measure field emission current from the electrode surface. Figure 3 shows a schematic view of this DC high gradient test stand and the geometrical shapes of the electrodes. Here, a test electrode piece can be changed, so that a variety of electrodes are easily tested. The dark currents can be measured under various field gradients which are set by the gap separation of electrodes (0.5~20mm) and the bias voltage (<150kV). This apparatus was also used to investigate the reduction method of dark current from the stainless-steel electrode of polarized DC-gun at Nagoya University.[5]

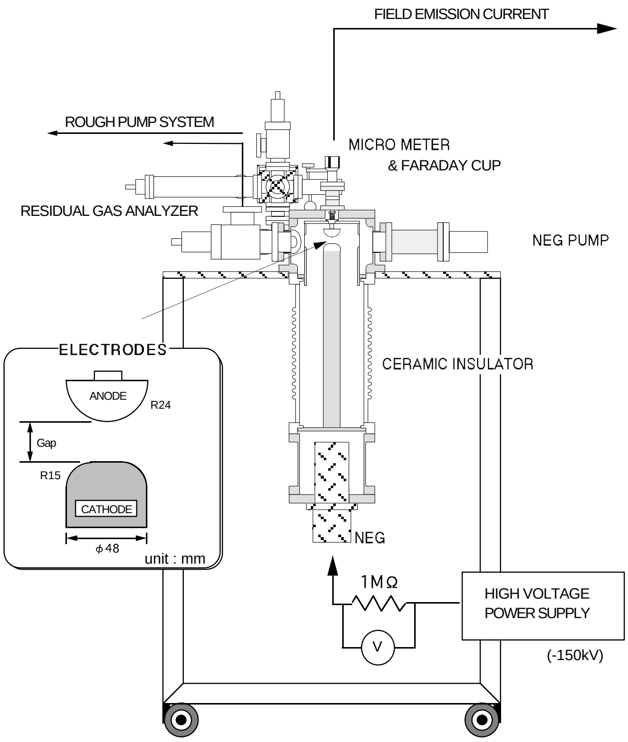


Figure 2 : Schematic view of DC high gradient test stand.

## 4 PRELIMINARY RESULTS

The first electrodes were made of class-1 OFHC copper with HIP, and the manner of preparation procedure was the same as sample 4 at table 1. The electrodes were installed carefully in the class 10 clean room, then the test stand was pumped down to the vacuum level of $10^{-11}$ torr after baking at 250 degree C for a week. In experiments, field emission currents were measured by changing the supplying voltage at the given gap length. After one measurement, the gap separation was changed and the next measurement was done. Figure 3 shows these results of dark current measurements obtained at the gap length of 0.5, 1.0, 3.0 mm. The surface field gradient of 28MV/m was achieved at the dark current level of 1nA for the gap length of 0.5mm. The value of maximum field gradient depends on the gap length, this effect may be attributed to the nature of the oxide layer made by the EP method. The microscopic enhancement factor $\beta$ was estimated by using a Fowler-Nordheim plot, as shown in Figure 4. The $\beta$ value of ~208 is consistent with those obtained by other group[5], but it is worse than our previous result, $\beta$~40, obtained from the super clean SUS electrode. [6]

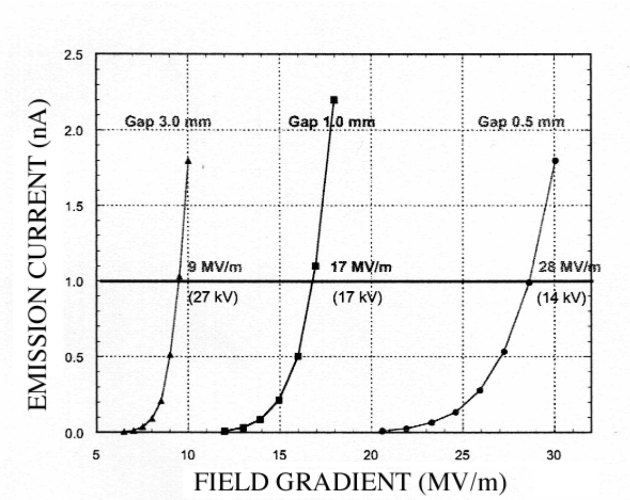


Figure 3 : Result of dark current measurement obtained for three different gap lengths.

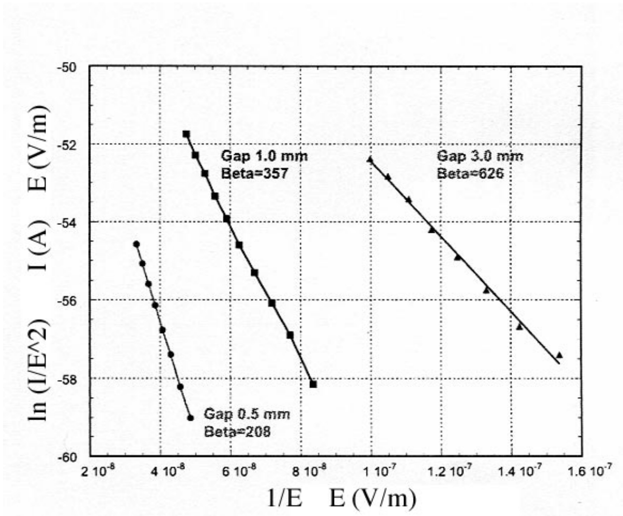


Figure 4 : Fowler-Nordheim plot of dark current measurements shown in Figure 3.

## 5 CONLUSIONS

The AES analyses for copper samples reveal that diamond-turning method using ethanol can achieve less contaminated surface than usual turning method. The EP is a powerful method for removing the impurities on the surface, but thick oxide layer is formed. At the preliminary DC high gradient test, EP electrodes achieved surface field gradients of 28MV/m with dark currents of 1nA. In order to achieve more higher field gradients, it is scheduled to measure field emission currents from two kinds of copper electrodes made by diamond turning with / without ozonized ultrapure water rinsing. After the establishment of the most effective surface treatment method, the fabrication of an RF-gun cavity will be started for the feasibility study of polarized RF-gun with the NEA photocathode.

## 6 REFERENCES


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