ACCELERATION OF COLD EMISSION BEAM FROM CARBON NANOTUBES IN KEKB/PF LINAC

S. Ohsawa[1,A)], M. Ikeda[A)], T. Sugimura[A)], and Y. Hozumi[B)]

[A)] Accelerator Laboratory, High Energy Accelerator Research Organization (KEK),

Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan

[B)] Advanced Manufacturing Research Institute, National Institute of Advanced Industrial Science and Technology (AIST),

Namiki 1-2-1, Tsukuba, Ibaraki 305-8564, Japan

Abstract

A field emission electron gun with a carbon-nanotube (CNT) cathode has been installed in the KEKB/PF linac, and the beams extracted from the gun have been accelerated to the end of the linac to 2.5GeV. We confirmed that the beams can easily stand comparison with the usually injected beams, which are extracted from a thermionic gun installed nearby.

INTRODUCTION

After the discovery in 1991, carbon nanotubes have been expected to be new types of cold field emitters with much larger stability, due to its unique material properties. We started joint researches with some companies in 2001 in order to develop high-density field emission electron guns with low emittances for future accelerators and other applications [1], [2].

We recently developed a field emission gun with a CNT-cathode [3], and achieved density beams of nearly 500 mA from a small cathode of 2.6 mm in diameter [4]. This time we accelerated field emitted beams to investigate what kinds of problems would occur in an actual linac for future applications.

FIELD EMISSION CNT-GUN

We developed a field emission CNT-gun for practical use in our linac, and made acceleration tests. This is the first report on the results.

Installation of CNT-gun

The CNT-gun has been installed in the KEKB/PF linac at the place very close to the PF-gun, which has being utilized for injection into the PF rings. The place is the point at about one third of the whole linac, therefore, both of the guns are out of the beam line in order to avid upstream coming beams for the KEKB storage rings. Both guns are set perpendicular to the beam line as are seen in Fig. 1, and being driven by a same high voltage modulator. But each of them has a grid pulser of one's own, and independently operates simultaneously. Due to lack of space, the CNT-gun has a small ion pump of a 10 *l*/min. pumping speed, which turned out to be insufficient, especially when discharges occurred at beginning of aging process.

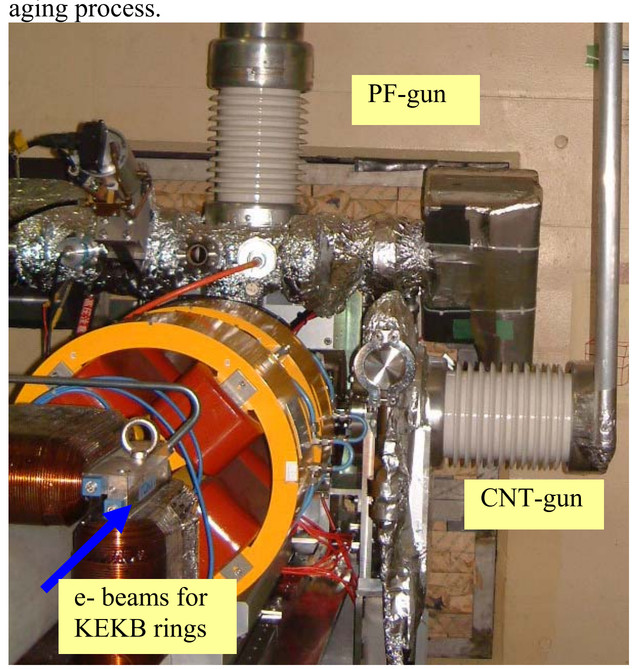

Figure 1: The CNT-cathode gun newly installed in the linac near the existing gun for injection into the PF rings.

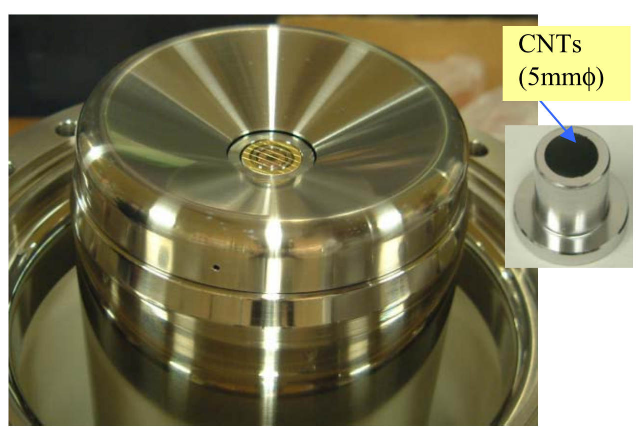

Figure 2: Structure of a field emission electron gun of triode-type with a CNT-cathode. CNTs are contained in a black portion on a cathode shown in a small right picture.

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CNT-gun Structure

The CNT-gun is a triode type which has a mesh grid electrode for current control. Figure 2 shows the grid-cathode assembly with a Wenelt electrode. The cathode electrode behind the grid has a shape shown in the small right picture, of which black portion of 5 mm in diameter is composed of randomly oriented carbon nanotubes. The cathode electrode can be easily replaced, when necessary, without changing other parts. This is one of features of our cold cathode electron gun which has no heater.

Beam Characteristics at Test Stand

Before installing the CNT cathode, we investigate the beam characteristics in a gun test stand at 100 kV, DC. The results of a sample cathode named SUS13 are shown in Fig. 3. The left-upper line shows the initial emission measured at the first scan with 2-ns pulses at 50 Hz, of which beam is shown in Fig. 4, and the other lower lines are measured after discharge happened in the first scan, which occurred when the negative bias voltage reached at 800V between the cathode and grid electrodes. Although the maximum current had decreased in the range of some hundred milliamperes from the CNT-cathode which area is a circle of 5 mm in diameter, we confirmed in several times measurements that the emission became stable with no more discharges in the scanned range. Then we installed the CNT-cathode/grid assembly in the CNT-gun in the linac and proceeded to acceleration tests.

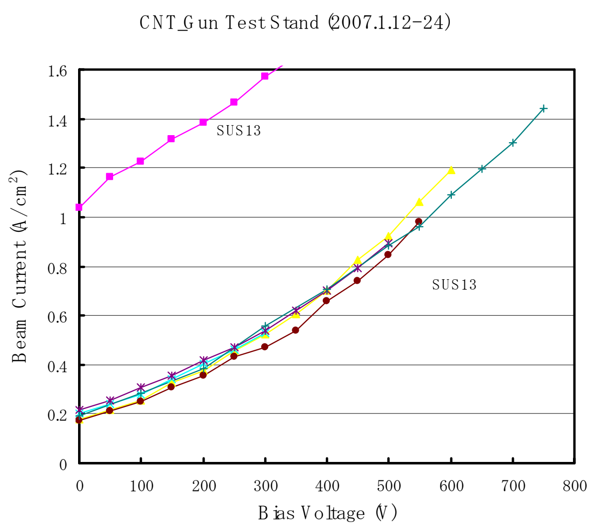

Figure 3: Current densities of the CNT-cathode utilized for the acceleration test.

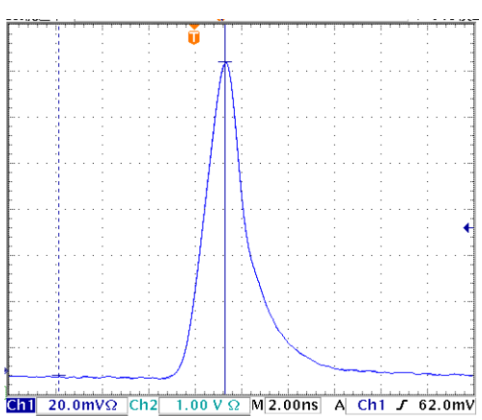

Figure 4: Pulsed beam shape from the CNT-cathode gun.

Acceleration Test in Linac

Electron beams extracted from the CNT-gun instead of the PF-gun have been accelerated up to 2.5 GeV in the linac, and emittances have been measured as well as energy stability with a screen in an analyser system at the end of the linac. Much difference was not found between the two beams from the different types of guns; namely, a field emission gun and a thermionic gun. Figure 5 shows a state of a typical beam extracted from the CNT-gun and accelerated in the linac. The charge transmission and orbits along the linac have no problems as well as beams of the PF-gun.

Beam emittances have been measured at 2.5 GeV near the end of the KEKB/PF linac by means of wire scanners. The results are listed in Table 1, for comparison, with typical values of usual injection beams which were extracted from the PF-gun. They are measured at the same beam charge. The emittance difference is thought to mainly come from the difference of cathode areas. These emittances should contain growth during the bunching and acceleration processes, and are thought to be far from the initial values at the guns.

We expected from the results shown in Fig. 3 that we could safely apply a bias voltage up to 500 V, and easily could extract a beam of up to 200 mA from the gun. But before reaching the voltage, discharges happened between the grid and cathode electrodes. This fact teaches us that for safety operation we should use the CNT-cathode at an electric field as low as possible without superimposing a negative DC bias voltage on negative pulses.

Table 1: Guns and beam emittances at 2.5 GeV

gun name and type	**area(cm^2)**	**$\gamma\varepsilon_x$,$\gamma\varepsilon_y$(π mm mrad)**
CNT-gun, field emission	0.2	52.8, 56.7
PF-gun, thermionic	2.0	68.1, 69.0

Raman Spectrum

Molecular structures have analysed by Raman shift. From the analysis of cathode samples, some interesting data was observed. The corresponding Raman spectra are illustrated in Fig.6. Both *D* band and *G* band are indicated at the characteristic wave numbers of 1350 and 1590 cm^{-1}, respectively. Each of brand-new cathodes (SUS14 and SUS15) has a spectrum with two clear peaks. On the other hand, used CNT-cathode which was damaged by discharges has a spectrum with much different structure: *G* band decreased and *D* band increased. Those changes might affect emission characteristics.

For carbon materials, the characteristic wave at the wave number of 1590 cm^{-1} represents the sp^2-bonding graphite crystal layer *G* band, while the wave peak at the wave number of 1350 cm^{-1} symbolizes the sp^3-bonding

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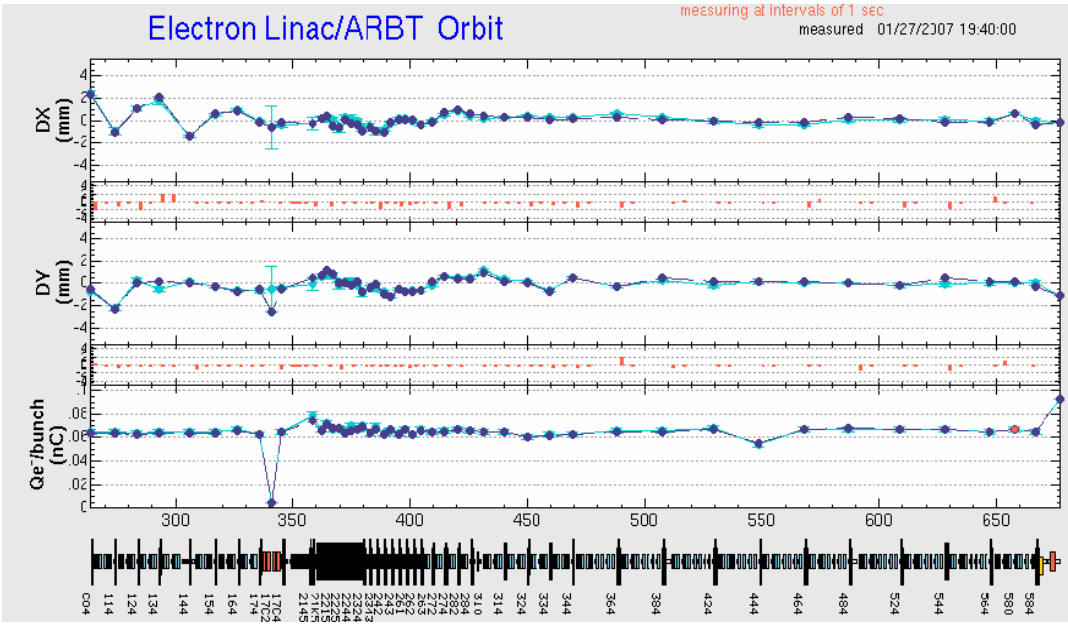

Figure 5: A typical example of the beams provided from the CNT-cathode gun. The lines show the electron beam x/y-orbits and charge transmission along the KEKB/PF linac.

Table 2: Initial DC emission (0.1mm gap, I=1mA)

Sample No.	Applied Voltage(V)	I_{max} (mA/cm^2)	G/D ratio in Raman Spectrum
SUS11	200	44.2	-
SUS12	207	57.5	1.11#
SUS13	213	43.7	-
SUS14	260	101.1	4.18
SUS15	194	40.3	2.39

measured after being used.

defective structure D band. The G band and the D band correspond to the conducting and the insulating structures, respectively. The intensity ratio of I_G/I_D signifies the degree of graphitization of CNTs. Therefore, the degree of graphitization is an indicator of electrical conductivity of CNTs. From our point of view, the higher the I_G/I_D value is, the higher the degree of graphitization and thus the electrical conductivity of the CNTs are.

The results of Raman analysis are summarized in Table 2 with initial emission data measured in a factory. All samples were made in same procedure and have same sizes. I_{max} is the local maximum charge density measured by scanning with an anode plate which has a hole of 20 µm in diameter. The cathode/anode gap distance and the average current I were kept at 0.1 mm and 1 mA, respectively.

CONCLUSIONS

The CNT-gun is almost ready for injections into PF storage rings. However, for daily usual operation, it is preferable to have ability to supply much more current for a margin as well as reliability without discharges. We should make some more efforts.

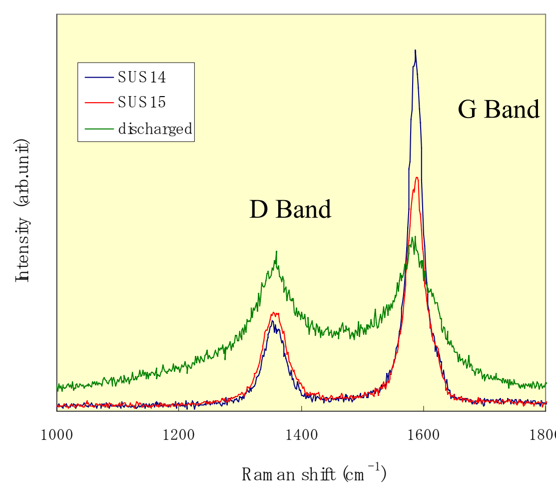

Figure 6: Raman spectra of the CNT-cathode samples.

ACKNOWLEDGEMENT

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