IPAC18

FRXGBD3

Application of Carbon Nanotube Wire for Beam Profile Measurement of Negative Hydrogen Ion Beam

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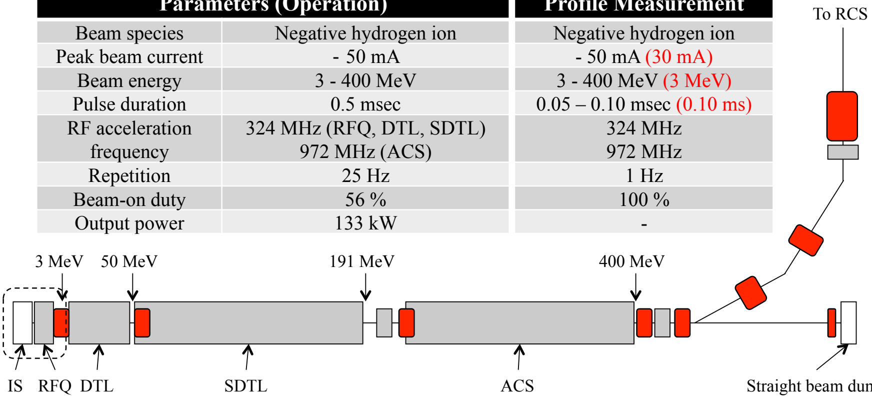
Introduction

- A wire-scanner monitor (WSM) is operated to measure the transverse beam profile for the quadruples tuning.
- Accelerated beam directly interacts with wire.
- Tungsten wire and carbon fiber are employed due to the high melting point.
- When the beam current is increased, another candidate material avoiding a fracture is required.
- Major objective of the study is to investigate another candidate material by the 3-MeV H^- beams.

Test Facility, J-PARC facility

J-PARC linac & its beam parameters

	Parameters (Operation)	Profile Measurement
Beam species	Negative hydrogen ion	Negative hydrogen ion
Peak beam current	- 50 mA	- 50 mA (30 mA)
Beam energy	3 - 400 MeV	3 - 400 MeV (3 MeV)
Pulse duration	0.5 msec	0.05 – 0.10 msec (0.10 ms)
RF acceleration frequency	324 MHz (RFQ, DTL, SDTL) 972 MHz (ACS)	324 MHz 972 MHz
Repetition	25 Hz	1 Hz
Beam-on duty	56 %	100 %
Output power	133 kW	-



J-PARC has two beam lines of 400-MeV linac to the experimental facilities and 3-MeV linac (RFQ-test stand) to the demonstration test.

Gray: Acceleration cavity
Red: Matching section

Carbon Nano Tube

Physical Properties of Wire Material

Material	Sublimation, Melting Point	Tensile Strength [N/mm²]	Thermal Conductivity [cal/cm/sec/℃]	Electrical Resistivity [Ωcm]
Tungsten	3,400 ^oC	1,000	0.39	5.5×10^{-6}
Carbon fiber		3,500	0.0225	$\sim 1.0 \times 10^{-4}$
Silicon carbide	2,700 ^oC	550	0.2887	$\sim 10^{3}$
Carbon Nanotube	3,000 ^oC	$2 \sim 5 \times 10^{6}$	4.77 ~ 7.16	$\sim 1.0 \times 10^{-6}$

Physical properties of carbon nanotubes (CNT)

- A tensile strength and an electric conductivity are higher, and hardness is endured thermally 3,000 ^oC.
- A density is 1.3 g/cm^3 which is almost half of graphite.

Carbon Nano Tube Wire

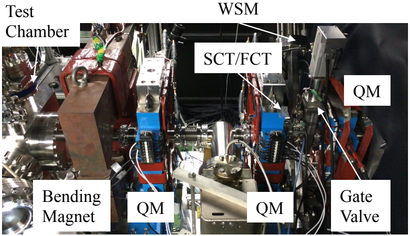
Physical Properties of CNT-Wire

Material	Sublimation, Melting Point	Tensile Strength [N/mm^2]	Thermal Conductivity [cal/cm/sec/℃]	Electrical Resistivity [Ωcm]
CNT-Wire	3,000 ^{o}C	500	0.215	2.0 x 10^{-3}
Single CNT	3,000 ^{o}C	2 ~ 5 x 10^{6}	4.77 ~ 7.16	~ 1.0 x 10^{-6}

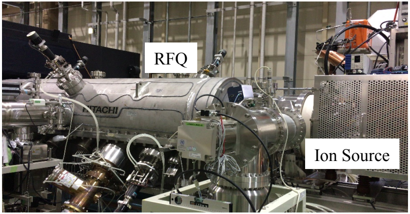
Physical properties of CNT Product

- CNT-wires (product) are made by spinning from a mixture of single- and multi-wall CNT.
- Single-wall CNT, the simplest CNT, has an ideal physical properties, and the structural chirality defines on the electrical conductivity.
- The commercial product is usually a mixture of the single- and multi-wall CNT which has multiple-different diameter concentric tubes.
- The wire product shows half- metallic and half-semi conductivity.

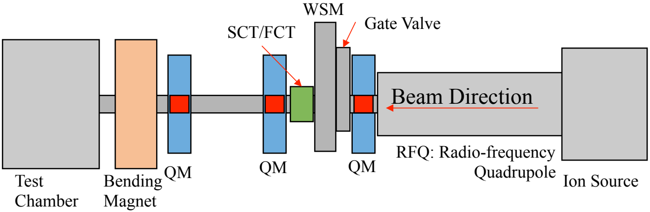
Test Facility, RFQ-test stand



Beam line of RFQ-test stand

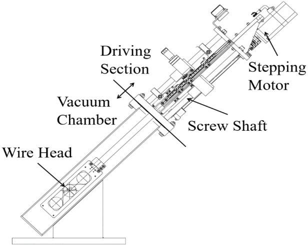


Ion source & RFQ

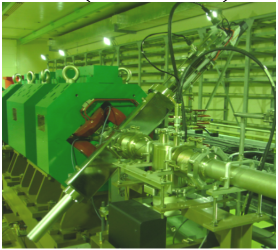


QM: Quadrupole Magnet
SCT: Slow Current Transformer
(Beam Current Monitor)
FCT: Fast Current Transformer
(Beam Current Monitor)
WSM: Wire Scanner Monitor
(Beam Profile Monitor)

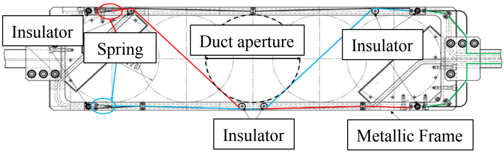
Beam Profile Monitor (WSM)



WSM Configuration



View of WSM Installation



Sensor Head of WSM

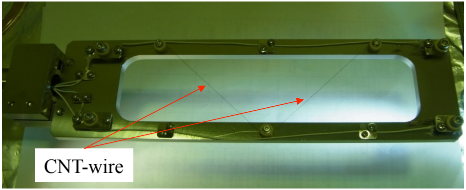
- CNT wires with three different diameters such as 30, 50 and 100 μmϕ are adopted.
- Because the wires are connected on a sensor head 45^{o} against the horizontal axis, both horizontal and vertical profiles can be measured in a stroke.

Test Parameters

CNT-Wire

produced by Hitachi Zosen Ltd. is set on the sensor head.

Diameter: 30, 50, 100 μmϕ

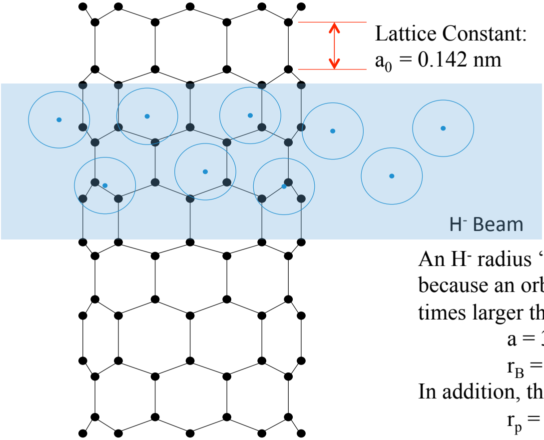


CNT mounted on a sensor head

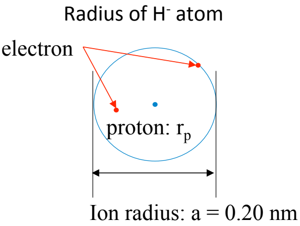
Beam conditions of tests

Properties	Value
Beam Species	Negative Hydrogen Ion (H^-)
Peak Beam Current (mA)	30 mA
Macro Pulse Width (μs)	50, 100, 135, 170, 200, 300, 400
Beam Repetition	1 shot, 1 Hz, 5 Hz

Mechanism of Signal Source



Carbon Nanotube



An H^- radius ‘a’ can be estimated to be 0.20 nm, because an orbit of a 1s’ electron of H^- atom is 3.8 times larger than Bohr radius (r_B),

$$a = 3.8\ r_B = 0.20\ \text{nm, here,}$$

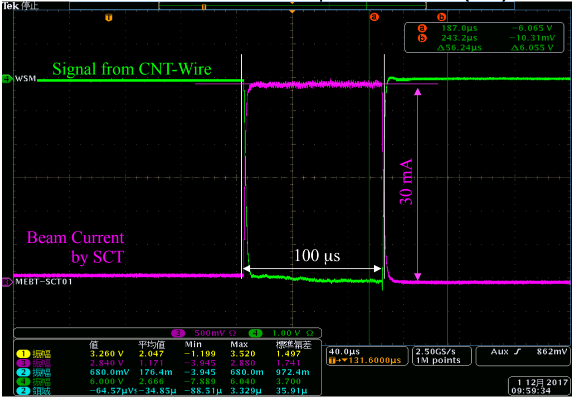
$$r_B = 0.529\times10^{-10}\ \text{m (Bohr radius).}$$

In addition, the proton radius of

$$r_p = 1.2\times10^{-15}\ \text{m.}$$

Electrons of H^- beam possibly collide the network of CNT because the radius of H^- atom almost corresponds with lattice constant.

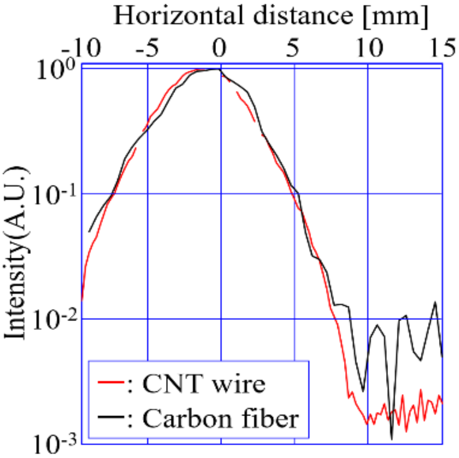
Signals from CNT wire by Beam (1)



Waveform of Signal from CNT Wire at 100 μs operation.

- An electron deposit is dominant to obtain a negative signal current obtained by an interaction between a beam and wire.

Beam Profile



Beam profile taken by CNT wire and carbon fiber

- Beam size in RMS

  CNT: 2.98 mm

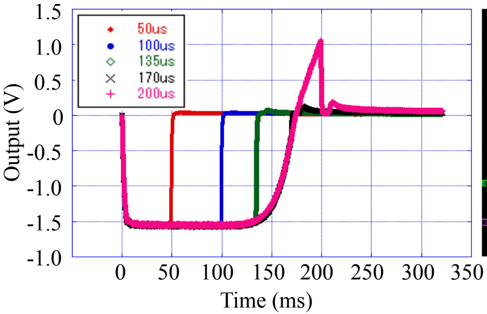
  Carbon fiber: 2.96 mm

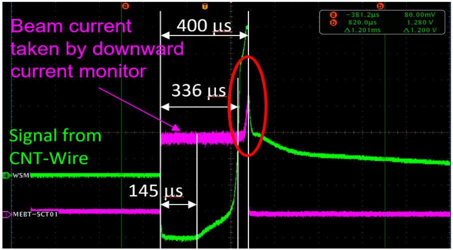
  Difference within 1.0 %.
- The background signal level of CNT is lower than that of carbon fiber.

  Background appear at

  10^{-2} to 10^{-3}.
- The cause is based on the signal value, and the biggest signal by CNT is 2.5 V and one by carbon fiber is 0.4 V.

Signals from CNT wire by Beam (2)

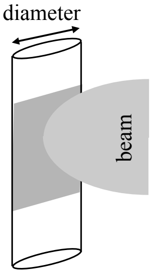




- When the pulse duration extended more than 145 µs, signal waveform turns to positive.
- When a big positive signal appears, downstream current monitor detects a signal which means secondary electrons goes through the monitor.

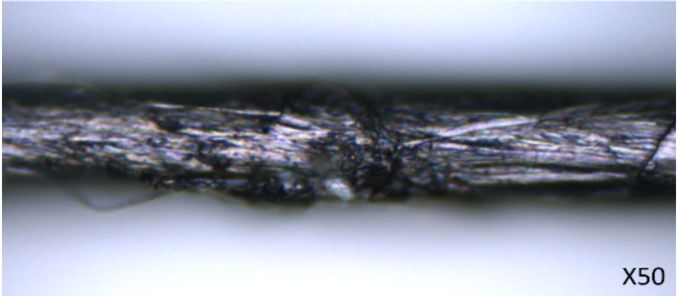
Signals from CNT wire by Beam (3)

Diameter (μmϕ)	Output (V)	Signal Current (mA)
30	1.1	0.51
50	1.5	0.71
100	2.5	1.17



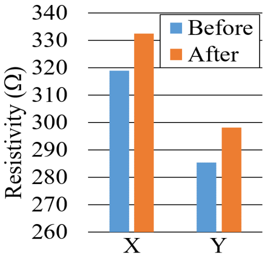
- The maximum signal gain can be at the point of Gaussian center.
- Signal should be proportional because a cross section between beam and wire depends on a cross-section of wire and beam diameter.

Damage

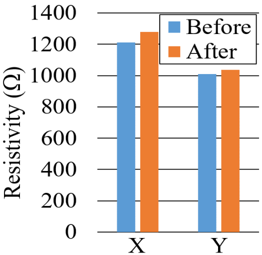


- Damage can be seen at the surface, however this wire can be operated after durability test.
- This is thought that the damage is not significant under this beam loading.

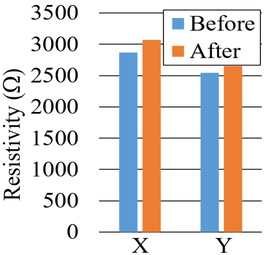
Damage



CNT : φ100 um



CNT : φ50 um



CNT : φ30 um

Before	After	rate
318.9	332.4	4.23%
285.4	298.1	4.45%

Before	After	rate
1212	1278	5.45%
1009	1037	2.78%

Before	After	rate
2866	3073	7.22%
2543	2650	4.21%

- Beams with 30 mA, 200 μs, and 5-Hz repetition for 4-mins. are irradiated at the Gaussian center of the beam.
- After the test, resistivity of all wires are increased from 2 – 7% which means a small damage occurred by the beam irradiation.

Summary & Conclusion

<Signal Gain>

- Beam profile taken by carbon fiber can be reproduced by CNT wire.
- The signal gain is enough high and the background became smaller, which led to improve the S/N ratio.

<Durability>

- Almost no damage can be observed on CNT wire in the excess high beam loading.
- The change of the resistivity which is associated with damage occurred, however the CNT can be still used.

Summary & Conclusion

< Conclusion >

- The CNT has an advantage to use a beam profile measurement in 3-MeV beam line.
- We are continuing a beam test of CNT wire at the high energy section and to trying to investigate a mechanism of the physical processes of signal and thermal electron generation.

< In future, …… >

- CNT wire will be tested in high energy beam line, i.e., 191 MeV beam test will be conducted.
- CNT wire will be tested by another beam particles, electrons, protons, ……, for the understanding of the physical process.