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DEVELOPMENT OF THE BUNCH SHAPE MONITOR USING THE CARBON-NANO TUBE WIRE

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Abstract

We are trying to develop the bunch shape monitor (BSM) using the carbon-nanotube wire (CNT) to measure the longitudinal beam profile of the high-intensity H⁻ beam with 3 MeV. The spark from the CNT wire was the serious problem for the operation, when the high voltage was applied to the CNT wire. The operation condition with stability was found up to about -5 kV by reducing the length of the wire and the charging-up considering the properties of the CNT. The bunch shape will be measured using the CNT-BSM with the new wire holder to suppress the spark.

INTRODUCTION

In the Japan proton accelerator research complex (J-PARC) linac, the H^- beam supplied by the ion source is accelerated to 400 MeV by the 3-MeV RFQ, 50-MeV DTL, 191-MeV SDTL and 400-MeV ACS [1]. Since the beam loss and the emittance growth would potentially occur when the beam current is increased, the more detailed measurement of the beam dynamics is necessary in the high-intensity operation. The beam tuning plays the important role to supply the high-intensity beam at the middle-energy beam transport (MEBT1) between the RFQ and the DTL, because the space-charge strongly affects the beam dynamics in the low velocity region.

Recently, the bunch shape monitor (BSM) was introduced to measure the longitudinal beam distribution at the MEBT1 [2] [3]. Figure 1 shows the schematic drawing of the BSM. When the wire is irradiated with the output H^- beam from the RFQ, the secondary electrons are produced. These secondary electrons are extracted by the electric field generated by the high voltage applied to the wire and transported to the subsequent RF deflector through the first collimator. The RF deflector modulates the electron beam from the phase to the position. The DC voltage is also applied to the electrodes of the RF deflector for the electrostatic-lens effect and the steering. The electrons matched to the phase of the RF field are selected by the second collimator. The bending magnet is used to select the electrons with the kinetic energy matched to the voltage applied to the wire. Finally the electrons are detected by the secondary electron multiplier (SEM). When the phase of the RF field is changed, the bunch width of the H^- beam matched with the RF phase is measured.

However, the normal tungsten (W) wire is broken for the high-intensity H^- beam with 3 MeV at the MEBT1 because

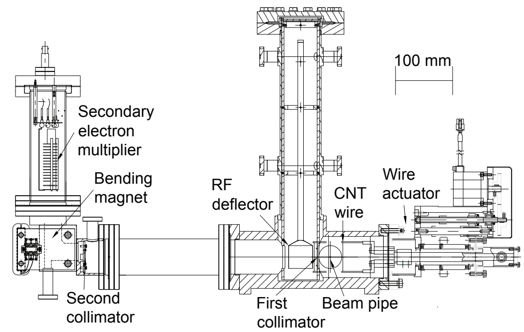

Figure 1: Schematic drawing of the BSM.

of the large energy deposit. The carbon-nanotube (CNT) wire [4] is selected as the strong wire to measure such high-intensity beam, since the CNT wire has a high-temperature tolerance [5] and a small energy deposit due to the low density compared with the W wire. The transverse beam profile of this high-intensity beam was measured with the wire scanner monitor using the CNT wire [6]. Therefore, the CNT wire is the good candidate for the BSM to measure the high-intensity beam. This presentation reports the current development status of the BSM using the CNT wire (CNT-BSM).

STUDIES OF THE CNT WIRE WITH APPLYING THE HIGH VOLTAGE

The CNT wire for this BSM is manufactured by Hitachi zosen Co.. The diameter, the density and the electric resistance are 100 μm, 0.56 g/cm^3 and 17.3 Ω/cm [7]. The high voltage should be applied to the CNT wire to extract the secondary electrons when the bunch shape is measured with the BSM. However, the electron emission from the CNT is known with applying the high voltage to the CNT [8] [9]. When the CNT wire was installed to the BSM, the spark occurred with increasing the pressure and the leak current, and the voltage could not be applied with stability. The surface of the CNT wire damaged by the spark was observed by the Keyence VK-X210 laser microscope [10]. Figure 2 shows images of surfaces of the normal and damaged CNT wires. When the wire is damaged, a part of the surface flakes off and the surface asperity is formed. Therefore, the spark should be suppressed as possible for the stable operation of the BSM to prevent the wire braking.

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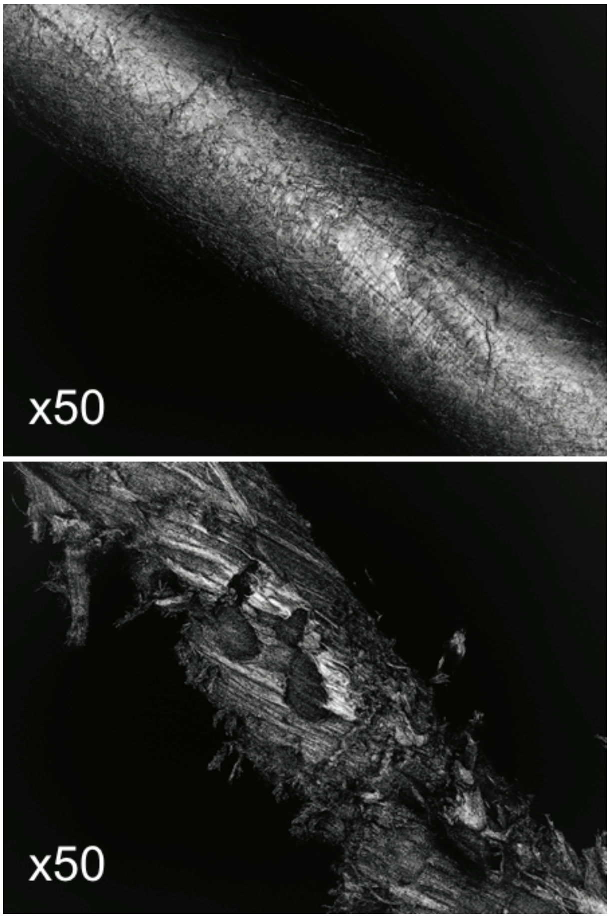

Figure 2: Images of the surface of the CNT wires by the laser microscope. The top and bottom figures show the normal CNT wire and the damaged CNT wire by the spark, respectively.

Spectroscopic Measurement

The spectroscopic measurement was carried out from the CNT wire with applying the high voltage. The Solid Lambda UV-NIR spectroscopic detector by Spectra Co. [11] was used to measure the wavelength of the luminescence. The sensor of the spectroscopic detector was fixed at the port of the beam pipe of the BSM through the view port made of the synthetic quarts to measure only the luminescence from the CNT wire. Figure 3 shows the measured wavelength distribution. The peak of the wavelength of 460 nm was observed in the Fig. 3. This luminescence is derived from the synthetic quarts exposed by the electron beam at the view port [12–15]. Therefore, the CNT wire actually emitted the electrons by the field emission and was one of causes for the spark.

Property Investigation of the CNT Wire

The high-voltage test for the CNT wire was conducted to identify the cause of the spark. Figure 4 shows the experimental setup of the HV test. The vacuum chamber was evacuated by a turbo-molecular pump and heated at around

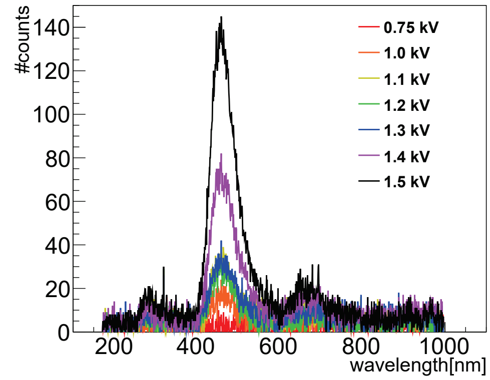

Figure 3: Result of the spectrometry when the voltage applied to the CNT wire was changed. The legend shows the applied voltage to the wire.

200 °C for about 9.5 hours. After this baking process, the pressure was reached to about 4×10^{-7} Pa or lower.

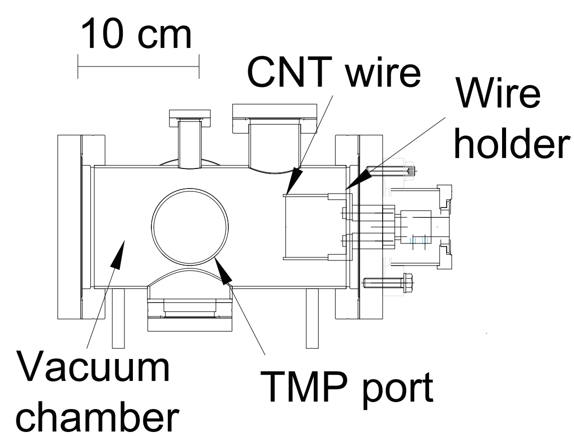

Figure 4: Experimental setup of the high-voltage test for the CNT wire.

If the CNT wire itself is the dominant cause of the spark, the increase of the pressure and the leak current is expected to be suppressed with the short CNT wire. The pressure and the leak current were measured by changing the length of the wire. Figure 5 shows the configurations of the CNT wires in the vacuum chamber. Figure 6 shows the summary of the pressure and the leak current from the CNT wire with applying the high voltage. The increase of the pressure and the leak current was suppressed with the short CNT wire as expected and then the spark was reduced with the short wire.

The other doubtful cause of the spark was the charging-up at the insulator. As a control measurement, the aluminum-foil cover was added to protect insulators from the emission electrons as shown in Fig. 7. In the Fig. 6, compared with the measurement without the cover, the pressure and the leak current were slowly increased with the cover so that the spark was suppressed up to around −5 kV with stability. Since electrons derived from the field emission already

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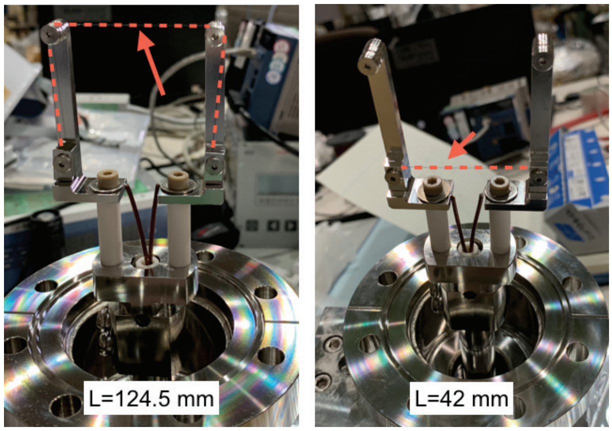

Figure 5: Configurations of the CNT wires. The red dotted line shows the CNT wire. L is the length of the wire.

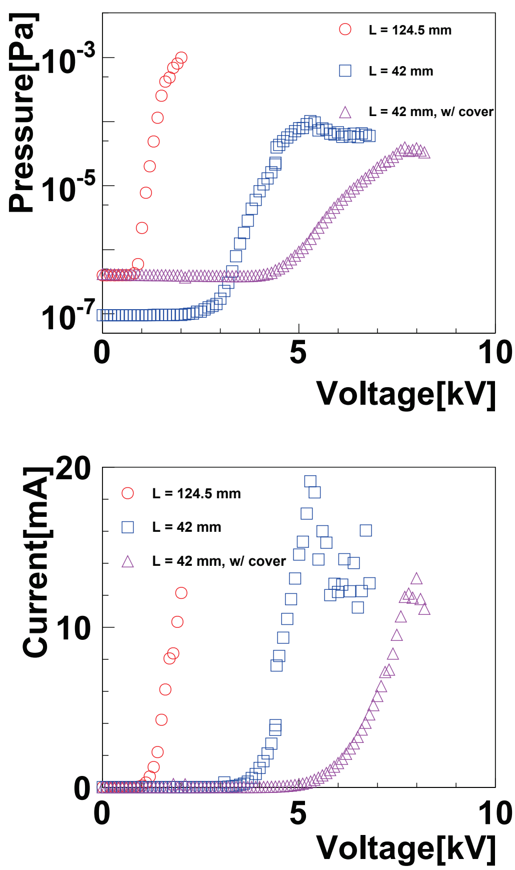

Figure 6: The pressure (top) and the leak current (bottom) with several lengths of CNT wires when the high voltage was applied. L is the length of the CNT wire. "cover" means the aluminum-foil cover to surppress the charging-up. The fluctuations of the pressure and the leak current were due to the spark from the CNT wire.

could be measured to the SEM when the voltage of −2 kV was applied to the CNT wire in another measurement, secondary electrons derived from the H^- beam is expected to be extracted with the voltage of around −5 kV for the wire. The new wire holder is being manufactured to use the short CNT wire and the metal cover to suppress the spark. The bunch shape of the high-intensity H^- beam with 3 MeV will be measured with the CNT-BSM using this new wire holder.

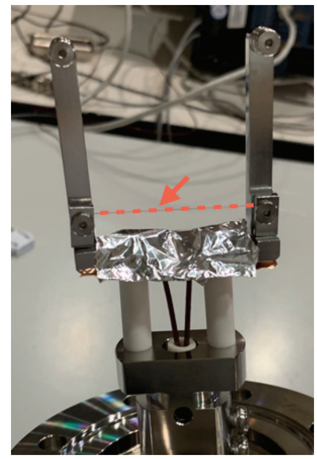

Figure 7: Configuration of the CNT wire with the aluminum-foil cover to suppress the charging-up. The red dotted line shows the CNT wire. The wire length is 42 mm.

SUMMARY

The longitudinal measurement will be realized for the high-intensity H^- beam with 3 MeV using the CNT-BSM. As a result of the investigation of the properties of the CNT wire, the CNT wire with applying the high voltage emits many elections and causes the spark. The operation condition up to about −5 kV without the spark was found by reducing the length of the CNT wire and adding the aluminum cover. The bunch shape will be measured using the CNT-BSM with the new wire holder to suppress the spark.

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