THE DEVELOPMENT OF A NEW TYPE OF ELECTRON MICROSCOPE USING SUPERCONDUCTING RF ACCELERATION

N. Higashi*, The University of Tokyo, Tokyo, Japan
A. Enomoto, Y. Kamiya, Y. Funahashi, T. Furuya, S. Michizono, M. Nishiwaki, H. Sakai, M. Sawabe
K. Ueno, M. Yamamoto, High Energy Accelerator Research Organization, Ibaraki, Japan
M. Kuriki, Hiroshima University, Hiroshima, Japan
S. Yamashita, ICEPP, The University of Tokyo, Tokyo, Japan

Abstract

We are developing a new type of electron microscope (EM), which adopts RF acceleration in order to exceed the energy limit of DC acceleration used in conventional EMs. It enables us to make a high-voltage EM more compact and to examine thicker specimens, and possibly to get better spatial resolution. It also provides an ability to observe transient processes by employing a state of the art laser photocathode technology as an electron source. But RF acceleration will increase an energy dispersion $\Delta E/E$ because of its sinusoidal field. So, we have designed a specially-shaped cavity in which the second harmonic filed (TM_{020}) is superposed on the first harmonic accelerating field (TM_{010}). To demonstrate the proof-of-principle of our concept, we are developing a prototype based on a conventional 300 keV transmission electron microscope (TEM) by employing a new photocathode gun and the 2-mode cavity for acceleration (Figure 1). The cavity was already fabricated and satisfied basic design parameters (Figure 2). A manufacturing process of the specially-shaped cavity was already established by our intense efforts. We are now fabricating the gun and a beam test will be carried out in this year.

MOTIVATION

Nowadays there are strong demands to observe materials like rare-metals and organic specimens including living organisms in situ, but it needs higher voltage than conventional EMs. But high-voltage EMs have a severe problem of discharge limitation. So we are now developing a new type EM that adopts RF acceleration, which has little problem concerning discharges. And there is a possibility to satisfy both of good spatial and temporal resolution. This has a great potential for the future of material science, biology, medical science and so on.

DIFFICULTY TO OVERCOME

Conventional EMs adopt electrostatic acceleration and have low energy dispersions $\Delta E/E$, e.g. 1.0×10^{-6}. If we replace it with RF acceleration, the spacial resolution becomes worse because of the large $\Delta E/E$ caused by a sinusoidal accelerating field. In order to overcome this problem, we have designed a specially-shaped superconducting (SC) cavity in which the second harmonic field (TM_{020}) is superimposed on the accelerating field (TM_{010}) so as to make a flat-crest of the RF field (Fig. 3). By using an SC cavity, a high accelerating field is available in CW mode, which has an advantage of getting a stable field and a current comparable to conventional EMs. In order to adopt RF acceleration, we also choose a photocathode as an electron source[1][2].

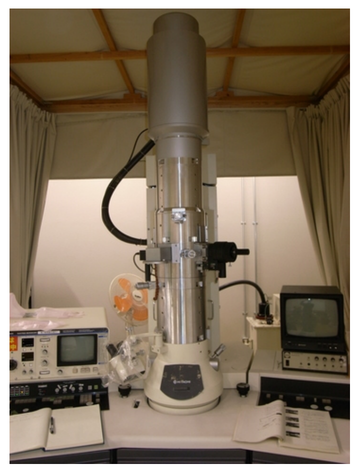

Figure 1: The existing TEM located in KEK.

Figure 2: The manufactured superconducting 2-mode cavity.

* higashi@icepp.s.u-tokyo.ac.jp

Table 1: 1-mode vs. 2-mode Acceleration. E_{ap} Means Axial Peak Value of Electric Field.

	E_{ap} of TM_{010}	E_{ap} of TM_{020}	E	ΔE	$\Delta E/E$
1-mode	9.85MV/m	-	304keV	61.8eV	2.04×10^{-4}
2-mode	8.21MV/m	9.25MV/m	278keV	10.2eV	3.68×10^{-5}

Table 2: Some Parameters in GPT

charge amount of each bunch	-1.0×10^{-16}C
initial beam size on the cathode	100μm
resonant frequency for TM_{010}	1.3GHz
resonant frequency for TM_{020}	2.6GHz
initial energy	0.15eV
space charge effect	included

DEVELOPMENT PLAN

Now we have a conventional 300 keV TEM in High Energy Accelerator Research Organization (KEK). For the feasibility study of the RF TEM, we are planning to make a 300 keV SC-RF TEM by combining the new RF cavity and the photocathode gun with the original optical system so as to minimize a cost and the human effort.

BEAM DYNAMICS SIMULATION

We have estimated the reduction of $\Delta E/E$ in the 2-mode acceleration by using General Particle Tracer (GPT) to the real electromagnetic field distribution of the new cavity and the photocathode gun. Some parameters are listed in Table 2. As the result, it has been found that we can reduce the energy dispersion $\Delta E/E$ from 2.04×10^{-4} to 3.68×10^{-5} with 2-mode cavity. Then we can get the spatial resolution of 376 pm, which is only about 50 % deterioration of the existing 300 keV TEM, which is much smaller than 818 pm, the expected value of 1-mode cavity. The required electric fields are 8.21 MV/m for TM_{010}, 9.25 MV/m for TM_{020} to minimize the spatial resolution (Table 1). The designed Q-values are 1.86×10^{8} for TM_{010}(1.3002 GHz), 1.00×10^{8} for TM_{020}(2.5999 GHz).

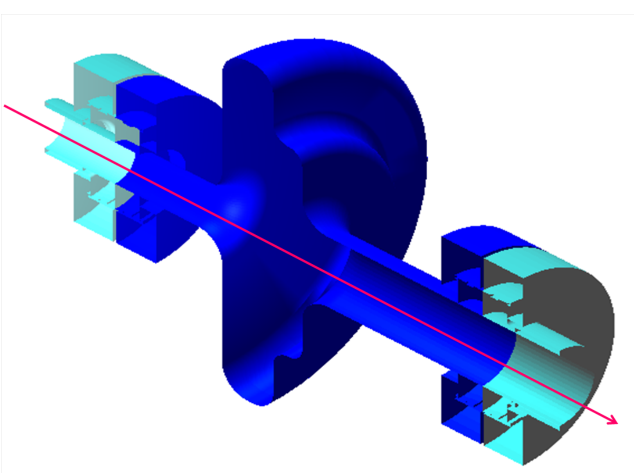

Figure 3: Schematic picture of specially-shaped cavity.

Table 3: Manufacturing Process of the Cavity

manufacturing niobium plates and lump
⇓
making two half cells by electron beam welding (EBW)
⇓
grind polishing inside half cells
⇓
electrospolishing (EP)
⇓
EBW on the equator of the cell
⇓
annealing
⇓
chemicalpolishing (CP)
⇓
high pressure washing
⇓
assembling
⇓
vacuuming

CAVITY MANUFACTURING

KEK has a lot of experiences and confirmed recipes for manufacturing RF accelerating cavities. This time, we have drawn on that, but searched for optimum methods and conditions. Our manufacturing process is summarized at Table 3.

We have used thicker niobium plate(2.8 mm∼13.0 mm) in order to make 2-mode driving stable. So we paid a lot of attentions to obtain the optimum conditions of electron beam welding (EBW). Because the cavity has quite different shape from ordinary ones, we could not employ rotating electropolishing (EP) that is very confirmed way in KEK. So we have conducted EP to saturate Nb half cells in the EP solution, only rotating cathode to flatten a quantity of polishing, which was about 70 μm. EP current density of 50 $\mathrm{mA/cm^2}$ was chosen to obtain the bright Nb surface. After we did EBW on the equator of the cavity, we conducted chemicalpolishing (CP), which removed about 33 μm.

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Table 4: The Result of Vertical Tests

	TM_{010}	TM_{020}
resonant frequency[GHz]	1.2963	2.5851
Q_0	$(1.41 \pm 0.45) \times 10^8$	$(0.89 \pm 0.18) \times 10^8$
$E_{\rm ap}[\rm MV/m]$	8.75±0.73	7.80±0.33

PERFORMANCE TEST

Two times of performance tests (cold tests) have been given in a vertical cryostat to the SC cavity so far. The accelerating gradient of TM_{010} was limited at (0.57±0.03) MV/m due to the hard multi-pacting (MP) in the first test. However, the gradient was improved to (8.75±0.73) MV/m after about 2 hours of conditioning in the second test. The summary of the tests is reduced to Table 4. The each error is systematic one come from power meters' instabilities and scales of oscilloscopes. The performance of a frequency tuner was also measured. The cavity has two tuners; one is "gap length tuner" which tunes frequencies roughly to tighten or release its bolts and can't be controlled outside the cryostat, and the other is "piezo tuner" which tunes finely to apply voltages to piezos and can be operated in a feedback loop (Figure 4). The tests shows that both tuners work properly, but its frequency ratio can't achieve the required value from the beam dynamics simulation, that is 2.

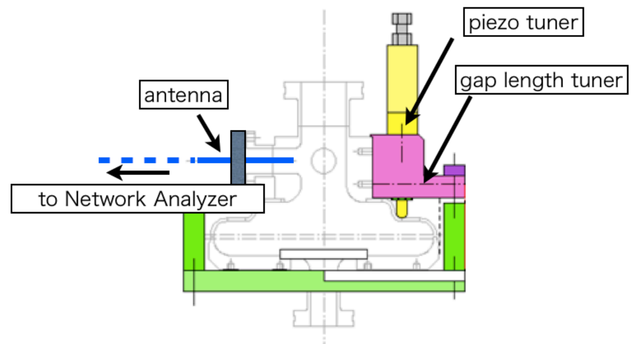

Figure 4: Two frequency tuners.

SUMMARY AND NEXT TASK

A new TEM of RF acceleration is considering in which a 2-mode SC cavity provides a flat-crest voltage in CW mode. The Beam dynamics simulation using GPT showed that 2-mode acceleration improves $\Delta E/E$ from 2.04×10^{-4} to 3.68×10^{-5}. A prototype cavity was fabricated and measured. It has showed that the required accelerating electric fields are almost achieved, and that the Q-values are very near to the simulation ones respectively, which means our manufacturing recipe of the cavity has been confirmed.

The next task is to modify the resonant frequencies to achieve the ratio to 2. For that, we are now trying to strain the cavity like Figure 5. And in parallel with that, we are now fabricating the gun. The goal of this year is to get a beam from the cathode.

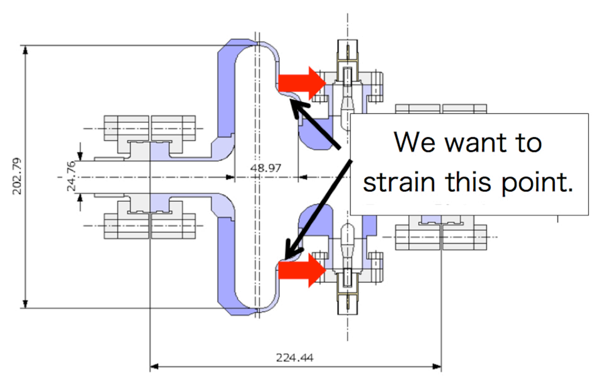

Figure 5: Next task to strain the cavity.

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