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DESIGN AND FABRICATION OF KEK SUPERCONDUCTING RF GUN #2

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Abstract

Superconducting RF gun can realize high acceleration voltage and high beam repetition. KEK has been developing the 1.3 GHz elliptical type 1.5 cell superconducting RF gun to investigate fundamental performance. A surface cleaning method and tools are developed by using KEK SRF GUN #1 and high surface peak gradient 75 MV/m was achieved without field emission. SRF GUN #2 equipped with the helium jacket and operable with electron beam was designed based on the SRF GUN #1. It can be operated with transmit type photocathode which include superconducting transparent material. The cathode rod is cooled by thermal conducting from the 2 K helium jacket and photocathode will be kept around 2K to maintain superconductivity. Bulk niobium photocathode rod, and substrate will used for the fundamental performance test. In parallel, the photocathode deposition chamber for multi-alkali photocathode will be prepared.

CAVITY DESIGN

The SRF GUN #2 cavity is 1.5 cell and 1.3 GHz shape designed based on SRF GUN #1. High gradient performance has demonstrated using SRF GUN #1. The maximum surface peak electric field (Esp) reached 75 MV/m [1]. The difference from #1 is that #2 has the helium jacket and the cathode rod size was changed for improving the cathode rod cooling. Figure 1 shows the #2 design. Table 1 shows the RF parameters of KEK SRF GUN#1. Yellow parts are made of niobium and green, blue parts are made of titanium and gray parts are made of stainless steel. Helium jacket can be connected by flanges with indium seal. The choke filter is placed as close to the accelerating cell as possible.

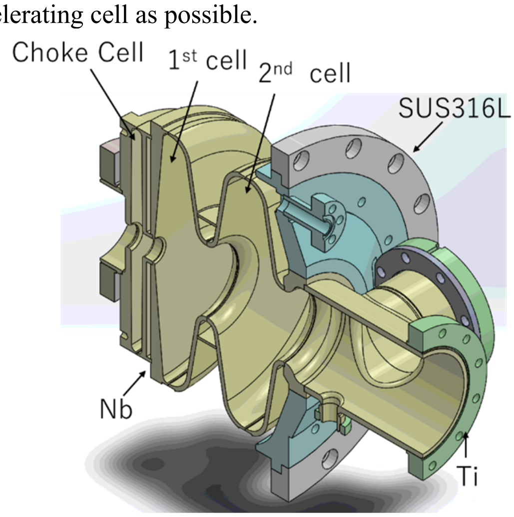

Figure 1: Design of KEK SRF GUN#2.

Table 1: RF Parameters of KEK SRF GUN#2

Parameter	Value
Frequency	1300 MHz
Geometrical factor	133.7 Ohm
Hsp/Esp	2.237 mT/(MV/m)
Z factor $(E_{sp} = Z\sqrt{Q_o P_{loss}})$	234.04

RF leakage from the choke filter is simulated using SUPERFISH because the cathode rod length was shortened. Figure 2 shows the simulation condition. Rod head is made of niobium, niobium surface resistance is set to 10×10^{-9} Ω. Other cathode holder parts are made of oxide free copper (OFC). Electrical resistivity of OFC is set to 1.68×10^{-8} Ω·m. Figure 3 shows the Q value dependence on the choke diameter. When the all surface is made of niobium the Q value is 1.3×10^{10}. The best diameter is 186.6mm. If 1% degradation is tolerated, lose is diameter fabrication tolerance set to ±0.2 mm.

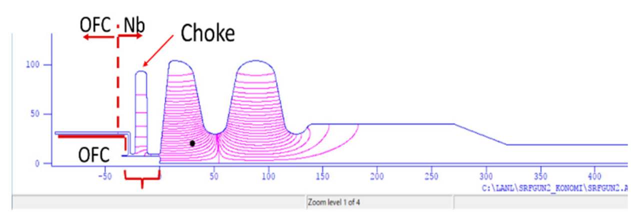

Figure 2: SUPERFISH simulation set up.

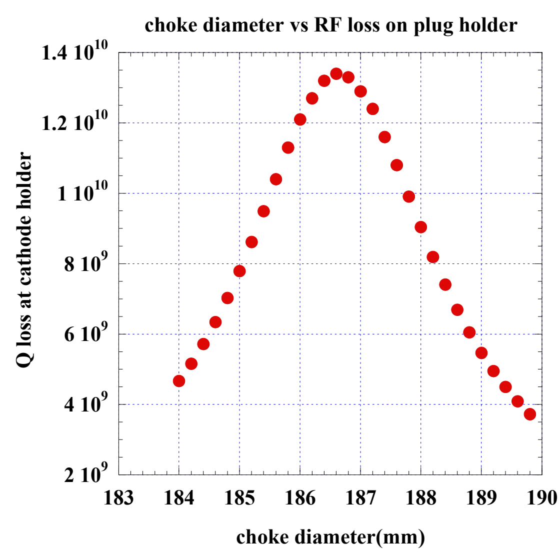

Figure 3: Q value dependence on choke diameter.

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CAVITY FABRICATION

The cavity fabrication was successfully completed (Figure 4). The three half cells of accelerating cell were press formed with the same die as used for SRF GUN#1. The choke cell and half-cell of 1st cell on cathode rod side were machined from bulk niobium. All parts other than stainless steel flange were connected by the electron beam welding. All parts are welded from the inside except for equator of the 2nd cell.

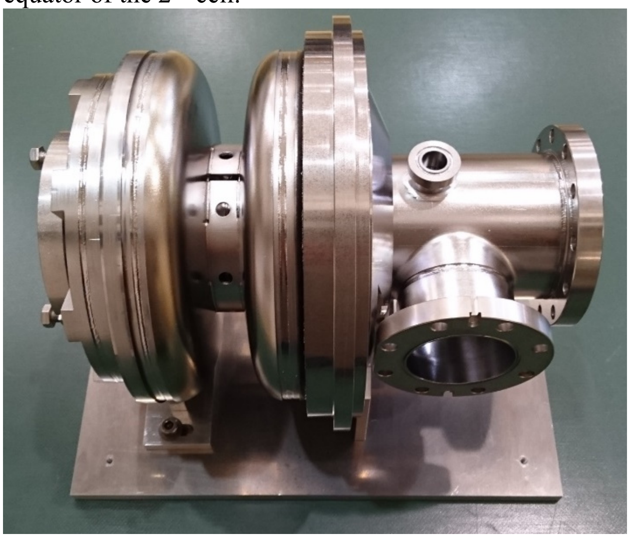

Figure 4: Fabrication completed SRF gun #2.

CATHODE ROD DESIGN

We plan to use a transparent superconductor for the substrate (LiTi2O4) of the photocathode. The transition temperature is 13 K. The cathode rod and holder were designed to cool down to around 2K. The cathode rod holder was designed as a part of the helium vessel. The cathode holder is made of copper block to ensure the thermal conductivity. The cathode rod is connected with flat and smooth surface for easily machining. Spring constant in the cathode rod is 71.21 N/mm. Maximum load is 71.21 N. contact area is about 450 mm^2. Contact pressure is about 158 kN/m^2. According to the solid works database, the thermal resistance is estimated to $1\times10^{-4} \sim 10\times10^{-4}$ m^{2}K/W [2]. Figure 5 shows the cooling simulation and thermal pass used CST.

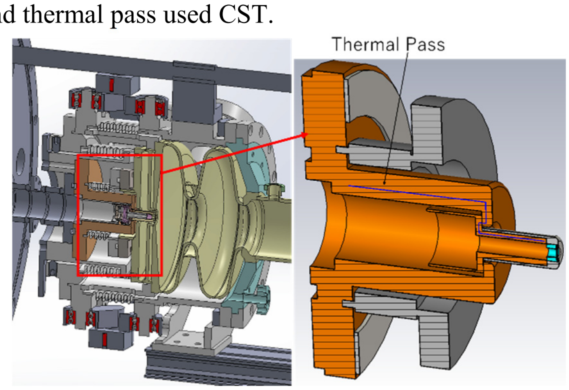

Figure 5: Image of SRF GUN #2 helium jacket (left), cathode rod and cathode rod holder for CST simulation (right)

Figure 6 shows the temperature of the cathode rod head. It can be cooled down to around 2.1 K if the thermal contact resistance is 1×10^{4} m^{2}K/W at connection. However, the thermal contact resistance is difficult to calculate, it is necessary to test using real structure. The machining of the cathode rod holder was completed. These parts will be connected by brazing in hydrogen furnace.

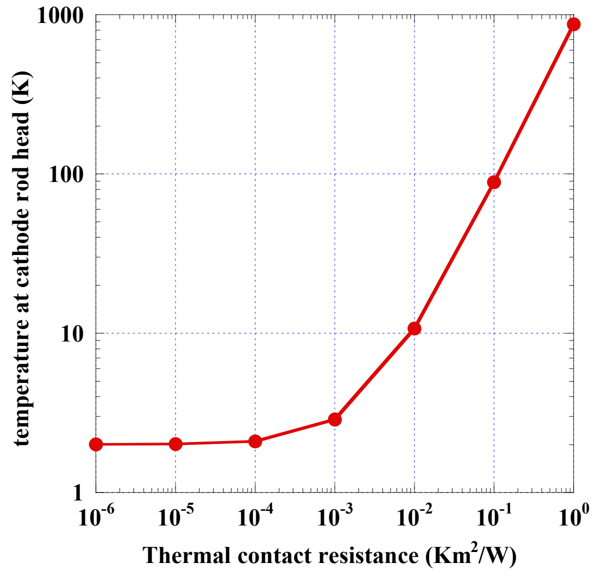

Figure 6: Cathode rod temperature dependence on the thermal contact resistance.

Figure 7 shows the design of the prototype cathode rod. The spring is made of Inconel. Inner parts consist the catching structure for connecting the transfer rod. Copper version of cathode rod was completed. Now we are fabricating the niobium cathode rod after a bit of modification. The K_2CsSb photocathode will be deposited on the head of the cathode rod. We want to use the transparent semiconductor substrate in future. The photocathode mount structure will be designed after proving thermal conductivity and RF performance of this cathode rod.

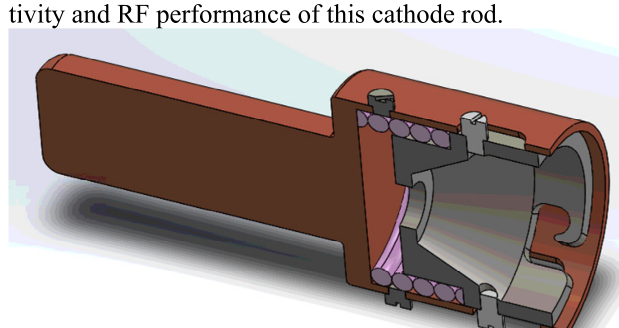

Figure 7: Prototype cathode rod design.

PHOTOCATHODE DEPOSITION CHAMBER

The photocathode deposition chamber was designed for connecting the cavity (Figure 8). The height of the cathode transfer line is aligned to same line of the gun. Deposition sources are SAES caesium dispenser, SAES potassium dispenser and bulk antimony heated by the tantalum

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wire. The cathode rod is heated and cleaned at 500 ºC by tantalum wire. The excitation laser can inject from front and back side during deposition. The excitation laser for gun operation will be injected to the photocathode through the deposition chamber during gun operation. The gate valve between gun cavity and the deposition chamber has the view port. The mirror is mounted bottom of the cathode rod holder.

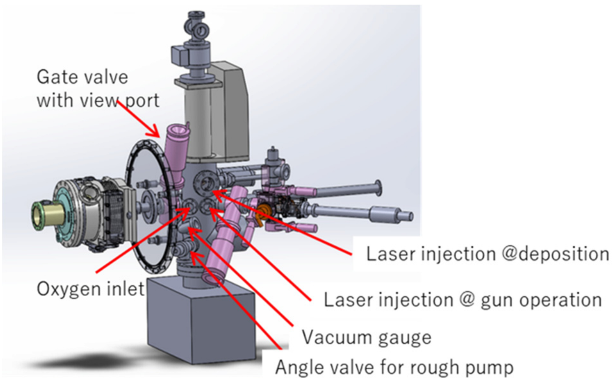

Figure 8: Design of the deposition chamber.

Figure 9 shows the deposition chamber. It should be assembled in clean room. This time, it was assembled for confirmation of assembly procedure and checking the photocathode performance. We plan to clean and reassemble in the clean room as soon as the performance is confirmed in the future. The chamber was vacuumed and baked. The chamber vacuum reached to 4×10^{-8} Pa. The main pump is ion pump which was opened to air several years. It was baked long time. We are now ready for photocathode deposition.

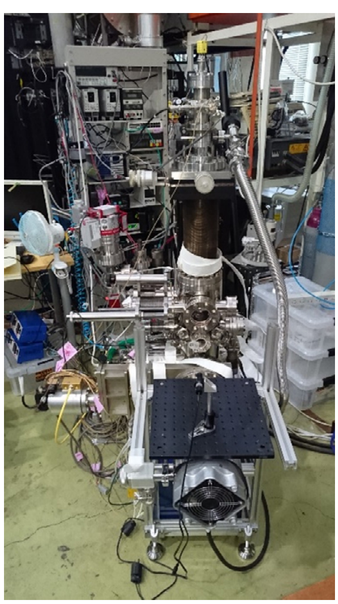

Figure 9: Assembled deposition chamber.

FUTURE PLAN

We are preparing the SRF gun #2 for the beam test using the horizontal cryostat which is operated for various cavities. Figure 10 shows the layout of the SRF GUN #2 in horizontal cryostat. The beam line and gun cavity will be inserted perpendicular to the longitudinal direction of the cryostat. The helium jacket and other parts are now under designing. First vertical test of the SRF GUN #2 will be carried out in this year. The gun cavity and cathode rod were designed focusing on cooling. Temperature of the cathode rod head is difficult to measure in the vertical test system. It is necessary to measure the cathode rod temperature directly in the vacuum using other chamber.

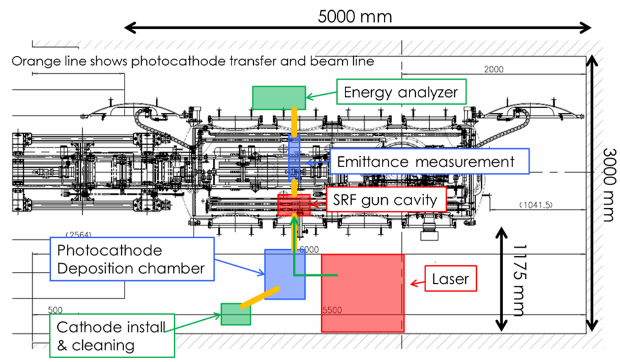

Figure 10: Layout of the SRF GUN #2 in horizontal cryostat.

SUMMARY

KEK has been developing the SRF gun. The fabrication of the KEK SRF gun #2 was successfully completed. Photocathode deposition chamber is also assembled. Vertical test of the gun cavity and photocathode deposition will be carried in this year. Other parts for the beam test is under designing. We are planning to test the beam performance using the horizontal cryostat existing at KEK.

REFERENCES

[1] T. Konomi *et al.*, "Development of SRF Gun Applying New Cathode Idea Using a Transparent Superconducting Layer", 59th ICFA Advanced Beam Dynamics Workshop on Energy Recovery Linacs (ERL2017), Geneva, Switzerland, Sep. 2017, pp.1-3.
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[2] SOLIDWORKS, http://help.solidworks.com/