DESIGN, FABRICATION AND PERFORMACE OF SRF-GUN CAVITY

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Abstract

KEK starts SRF gun development for studying the ERL light source from 2013. The target beam parameters is that beam current is 100 mA, repletion rate is 1.3 GHz CW and normalized emittance is less than 1 π.mm.mrad, pulse length is 3 ps. The shape of acceleration cells is elliptical and the electron emitter is photocathode. Acceleration cell and cathode head was shorted by a choke cell. A beam emittance deeply depends on the laser profile. The excitation laser is injected from backside of the photocathode to shape the laser profile easily by short focal distance. The photocathode has three layers. A substrate is $MgAl_2O_4$. A middle layer is $LiTi_2O_4$ which has two features of transparency and superconductivity. A surface layer is K2CsSb bi-alkali photocathode. The superconductivity protects the substrate from brake down. The cavity shape was designed by the SUPERFISH and GPT. The iris radius is ϕ 60 mm. The beam parameters satisfy target values. Prototype #1 cavity was fabricated without choke, cathode plug and photocathode. 1st vertical test was done. The surface peak electric field reached Esp=66 MV/m, Qo=4.19×10^9. This meets the target value Esp=42 MV/m Qo=4.5×10^9 sufficiently.

CONCEPTUAL DESIGN

Electron gun is a key component of the linac. Normalized emittance is dependent on thermal emittance of photocathode and space charge effect at low energy region. It is necessary to generate narrow energy distribution electrons and to accelerate high gradient on cathode to achieve the lower emittance beam. Thermal emittance can decrease at low temperature. Space charge effect can be suppressed by shaping profile of excitation laser. Transparent photocathode can be controlled the laser shape easily because of short focal length. Combination of SRF gun and transparent photocathode is suitable for high repletion and low emittance gun. The transparent photocathode needs the high durability under high electric RF field. A transparent superconductor $LiTi_2O_4$ which is epitaxially grown on the transparent substrate $MgAl_2O_4$ reflects the RF and transmits excitation laser [1]. Photoelectric surface is K2CsSb. It is well known as high quantum efficiency material.

Target beam and cavity parameters are listed in Table 1. These parameters based on KEK 3 GeV ERL project. Beam energy is determined from the input coupler [2]. Surface peak electric field is designed less than 50 MV/m. The cavity shape was designed based on the HZDR and HZB SRF gun [3],[4].

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Table 1: Target Parameters of the SRF Gun

Parameter	Value
Beam energy	2 MeV
RF frequency	1.3 GHz
Beam current	100 mA
Pulse length (1σ)	3 ps
Projected emittance	< 1 π mm mrad
Projected energy spread	< 0.1%
Number of cells	1.5

CAVITY DESIGN

The cavity design was started from analysing relation between cavity shape and beam parameters [4]. Beam performance is affected by initial slope of the electric field and cell length. Diameter of the end iris lightly affects to the beam performance. When beam energy set to 2 MeV, it is possible to suppress the surface peak electric field in less than 50 MV/m. Half cells shape besides the cathode side half-cell were designed by same shape to supress die fabrication cost. Electric field distribution on beam axis is shown in Fig.1.

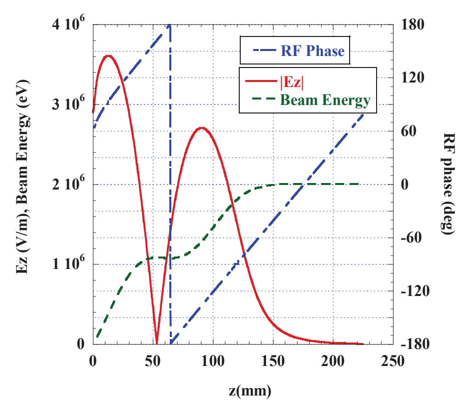

Figure 1: RF electric field and beam energy on beam axis.

Initial configuration of GPT is that beam distribution is uniform, beam radius is ϕ2 mm, beam length is 10 mm, number of macro particle is 1000, and energy distribution is 0.4 eV. Space charge effect is simulated by using “spacecharge3D”. RF filed was imported from SUPERFISH. Best initial RF phase and accelerating gradient was determined from an intersection point of 2 MeV bam energy curve and minimum projected energy spread curve (Fig. 2). Best parameters are calculated by

ISBN 978-3-95450-178-6

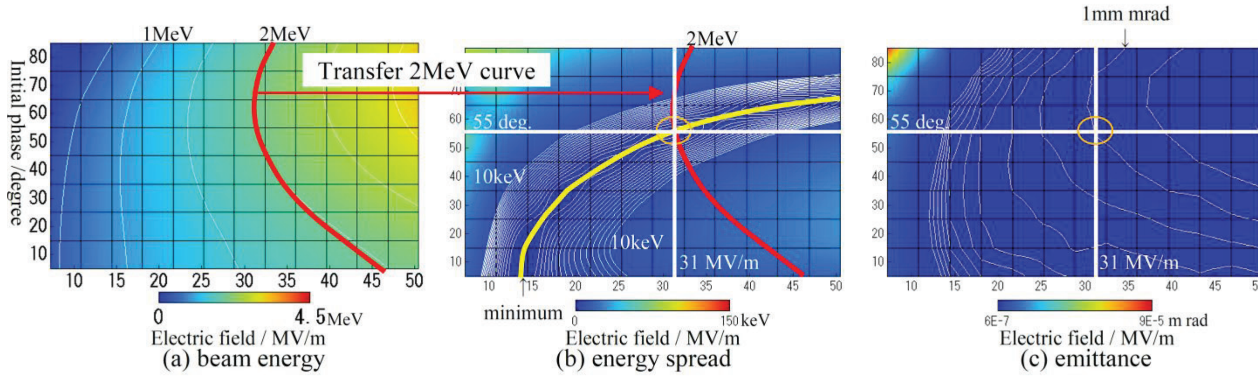

Figure 2: Contour map of beam specifications at cavity exit.

the condition that number of macro particle is 50,000 because the "spacecharge3D" effect converges around this number. The best beam parameters and cavity parameters are listed in Table 2. Filed distribution of the SRF gun by SUPERFISH was shown in Fig. 3. The target value of surface resistance was set as 30nΩ from the experience of ILC cavity development. Q value is 4.5×10^9 and wall loss is 8W at the target gradient.

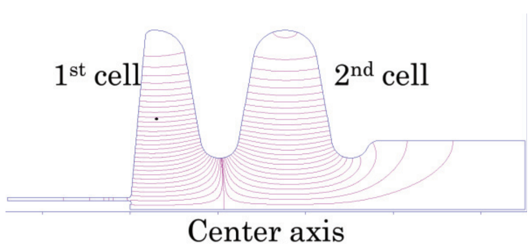

Figure 3: RF electric field analysis by SUPERFISH.

Table 2: Beam and Cavity Parameters

Parameter	Value
Beam energy	2 MeV
RF frequency	1.3 GHz
Projected emittance	0.7 mm mrad
Projected energy spread	1.7 keV
Surface peak electric field	41.9 MV/m
Surface peak magnetic field	95.2 mT
Initial RF phase	55 deg.
Geometrical Factor	135.6 Ω

PHOTOCATHODE

In order to achieve durability to RF compatible with transmittance of light, transparent superconducting $LiTi_2O_4$ layer is inserted to the photocathode. Surface magnetic field on the photocathode is lower than 4.3 mT in the SRF gun. Critical magnetic field of $LiTi_2O_4$ which thickness is 114 nm, was measured by using SQUID (Quantum Design, Inc. MPMS-7). Before and after forming bi-alkali K_2CsSb surface, H_{c1} slightly decrease, but it can be maintained superconducting state under operate less than 5K (Fig. 4).

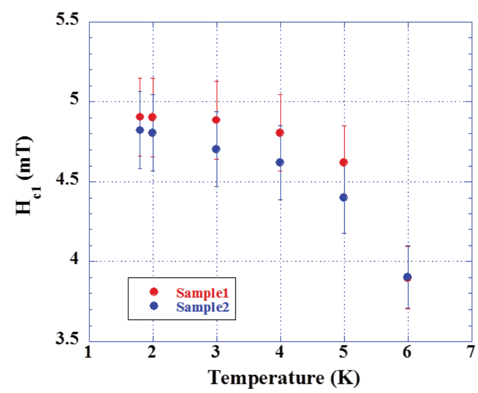

Figure 4: Lower critical magnetic field (Hc1) of LiTi2O4. Sample 1 is before forming bi-alkali layer. Sample 2 is after forming bi-alkali layer.

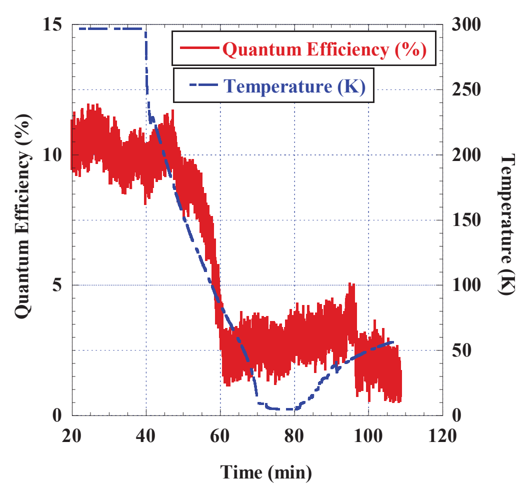

Figure 5: One example of the cooling test of the photocathode in DC gun.

It is necessary to confirm the durability to the low temperature of the bi-alkali to operate at 5K. Cooling technique of $LiTi_2O4+K_2CsSb$ is tested in DC gun with cryostat (Fig. 5). Quantum Efficiency decrease rapidly under cooling. Degree of vacuum and beam current and cathode voltage seem related to this result. Therefore, the base material of cathode rod is copper to cool the photocathode. The Surface is covered by niobium.

FABRICATION OF SRF GUN #1

SRF gun #1 is designed for vertical tests. Vertical tests are planned to evaluate each part of the SRF gun. At first, SRF gun #1 was fabricated without choke and cathode rod and photocathode to test the shape of the accelerating gradient and to develop the cleaning techniques. The iris diameter for the cathode rod is smaller than necessary design for cooling the photocathode. The half-cell of photocathode side was fabricated by cutting work to increase stiffness. The others three half cells were fabricated by press forming from same die. Diameters of the beam pipe, input coupler port, pickup port and cathode rod port were selected same size of KEK SRF cavities. All parts are welded by the electron beam welding (Fig. 6).

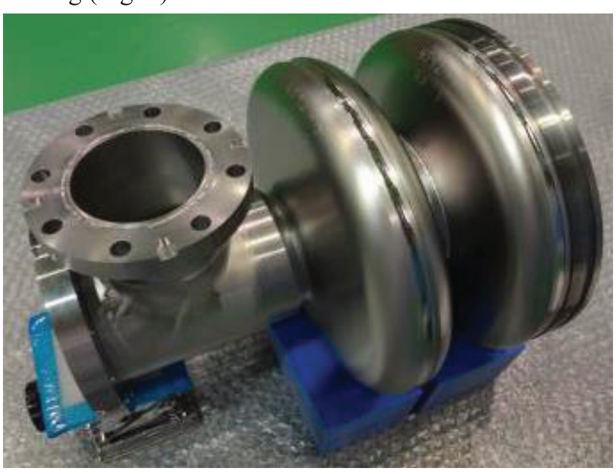

Figure 6: First step of SRF GUN #1.

PREPARATION FOR VERTICAL TEST

Preparation method of the SRF gun #1 followed the ILC cavity. At first, surface was removed 106μm by chemical polishing after fabricating the cavity. Ratio of the chemical polishing solution is HF: HNO_3: H_2PO_4 = 1:1:2. The chemical polishing solution was stored in the cavity without circulating. An agitating blade was used to polish uniformly. The cavity was annealed at 750 ^oC x3 hours in vacuum with titanium box because of removing the H_2 in niobium and stress of fabrication. The cavity frequency and filed distribution were tuning by using bead method. When filed distribution is tuned, the cathode side cell was fixed by the supporting jig. After the tuning, the error of the filed distribution was less than 1% (Fig.7).

20 μm surface was removed by electro-polishing as the final surface polishing (Fig.8). Ratio of electro-polishing solution is H_2SO_4(98%): HF(48%) =10:1. The electro-polishing solution was stored in the cavity without circulating. The volume of the solution is 3.1 L and inner surface area of the cavity is 1979 cm^2. A cathode was made of pure aluminium. It had blades and was rotated during the polishing. Polishing current and voltage were 50V and 25 A. A Polishing thickness was calculated from product of time and current.

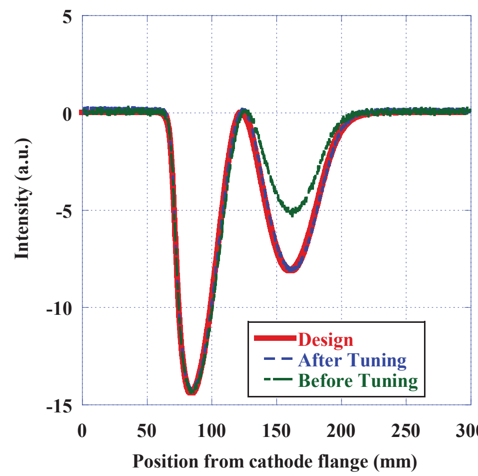

Figure 7: Electric filed distribution of the SRF gun #1.

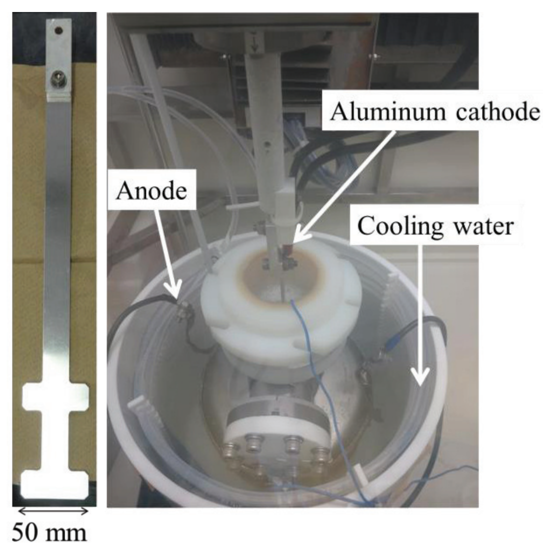

Figure 8: Vertical electro-polishing of the SRF gun #1.

After the electro-polishing, ultra-sonic rinsing and high pressure rinsing were done. Bath temperature of the ultra-sonic rinsing is 51 ^oC. Rinsing time is 15 minutes. A nozzle head of the high pressure rinsing was designed for the SRF gun #1 to hit water jet to the cathode side cell (Fig. 9). The angle of the nozzle is 5, 70, 90, 110 degree from the cathode cell side. Nozzle diameter is ϕ 0.6 mm. Pressure of water is 8 MPa. Rinsing time is 2 hours. The cavity is carried to a clean room (ISO class 4) immediately after the water on the outer surface was

ISBN 978-3-95450-178-6

removed. The cavity was assembled in the clean room and baked 130C × 44 hour.

Figure 9: Special nozzle head for high pressure rinsing.

RESULT OF THE 1ST VERTICAL TEST

Surface peak electric field is used instead of accelerating gradient which can't be defined because Lorentz factor β is shift in the SRF gun. Fig.10 shows the result of vertical test. This cavity has only accelerating cell without choke, cathode rod and photocathode as mentioned earlier. Surface peak field reached to 66 MV/m and Qo is 4.3×10^9. At the target filed 41.9 MV/m, result of Qo is 7.15×10^9 and meets the target value 4.5×10^9. Although filed emission on set is 50 MV/m, it is higher than target field.

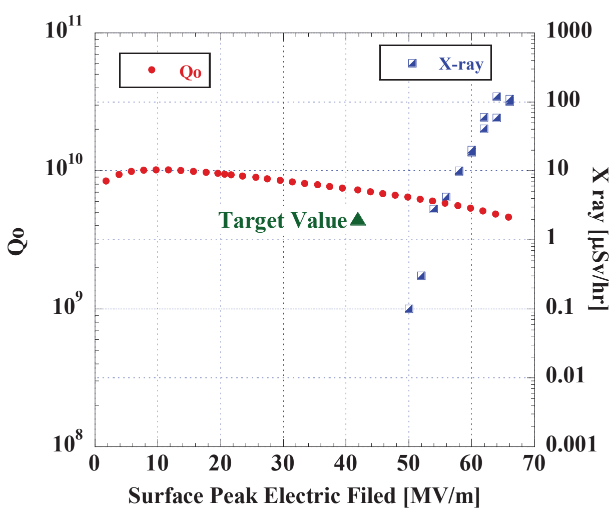

Figure 10: Vertical test of the accelerating cells of SRF gun #1.

The inside of the cavity was observed after the vertical test, color at the centre of the cathode cell was changed (Fig. 11). This problem can be observed even when vertical test was stopped by 2MV/m. The cathode cell niobium is guaranteed high RRR by the material manufacturer. We will investigate the reason.

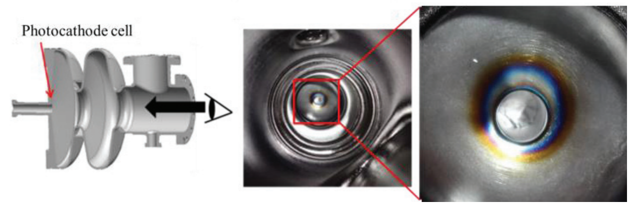

Figure 11: Color change of the cathode cell.

SUMMARY

SRF gun#1 was designed to satisfy the ERL beam parameters. The photocathode for backside excitation has been developed. There is a problem that the quantum efficiency decreases during cooling. It is necessary to improve cooling method for a solution of this problem. SRF gun #1 cavity was fabricated without choke and cathode rod. Result of the vertical test was met the target values. Next step of the cavity test is added the choke cell.

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ISBN 978-3-95450-178-6