ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOIACC002

DEVELOPMENT OF SRF GUN APPLYING NEW CATHODE IDEA USING A TRANSPARENT SUPERCONDUCTING LAYER

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Abstract

KEK has been developing a superconducting RF gun for CW ERL since 2013. The SRF gun is a combination of a 1.3 GHz, 1.5-cell superconducting RF cavity and a back-side excitation type photocathode. The photocathode consists of transparent substrate $MgAl_2O_4$, transparent superconductor $LiTi_2O_4$ and bi-alkali photocathode K_2CsSb. The reason for using transparent superconductor is to reflect RF by using the feature of penetration depth of superconductor, which is defined from London equation. It protects optical components from RF damage. The critical DC magnetic field of the cathode, quantum efficiency and initial emittance were measured. These show the cathode can be used for the SRF gun. The gun cavity was designed to satisfy the photocathode operation. Eight vertical tests of the gun cavity have been performed. The surface peak electric field reaches to 75 MV/m with the dummy cathode rod which was made of bulk niobium.

INTRODUCTION

The SRF gun is a key device for the future linac base electron accelerator. KEK start a SRF gun development for KEK 3 GeV ERL project [1]. We apply the backside excitation scheme. There are two advantages. One is RF and beam line structures are simpler than conventional design using metal substrate photocathode. It is not necessary to bend the excitation laser or electron beam trajectory so as not to overlap each other as compared with the front excitation. Second advantage is that the excitation laser is able to be controlled more precisely and increase the pointing stability by using short focal length lenses. It helps the space charge effect compensation.

PHOTOCATHODE IDEA

In order to develop the back side excitation photocathode, it is necessary to use a transparent substrate such as sapphire glass. However SiC and GaN substrate seems to be difficult to operate in a high RF voltage because breakdown field is 3.5 MV/cm [2]. And RF leakage to back side of the photocathode is a risk of damaging a light fibre and lens mounted at the back of the photocathode. The photocathode substrate should have the metallic properties to reflect the RF in order not to reduce the electric field on the photocathode. It increases the initial electric gradient at low beam energy and suppresses the space charge effect.

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We propose a photocathode using a transparent superconductor (Fig.1). It is suit to the superconducting technology. A transparent superconductor $LiTi_2O_4$ can block the RF leakage and transmit the excitation visible light at the same time [3]. RF penetration depth of superconductor is defined by London penetration depth. It is about several tens of nanometers. LiTi2O4 is an epitaxial thin film deposited by pulsed laser deposition on $MgAl_2O_4$ (111). The transition temperature is about 12 K. The transmittance is about 70% at a wavelength of 477 nm. The lattice constant is 0.8405 nm. It is close to the famous photocathode surface K_2CsSb (0.861 nm) [4].

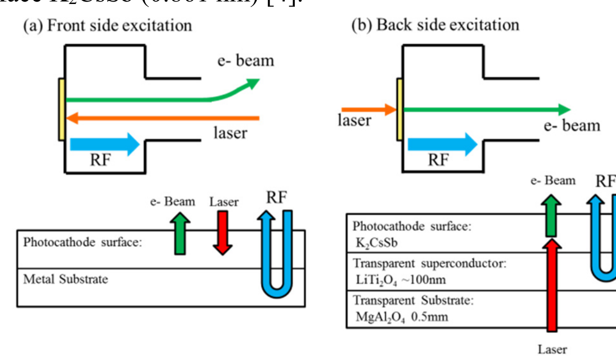

Figure 1: Front and back side excitation type photocathode structure. (a) Conventional method using metal substrate. (b) Transparent photocathode using a transparent superconductor.

SRF GUN CAVITY PERFORMANCE

The superconductor used in the photocathode needs to be cooled down. The SRF gun cavity also operates at 2 K. an effective cathode cooling system could be designed. MHI and KEK designed the KEK SRF gun #1 to test the maximum electric field and Q value [5]. It consists of 1.5 accelerating elliptical cells, choke cell and cathode plug. First cells are designed with the cathode cell to test. The accelerating cell shape was designed to minimize the energy spread and emittance by adjusting the cell taper angle. Table 1 shows the parameters of the KEK SRF gun #1. Target Q values are estimated from ILC target. Peak electric and magnetic field located on accelerating cell. On the photocathode, maximum electric field is 70% of the peak electric field of the accelerating cell and maximum magnetic field is 3.3 mT.

Figure 2 shows the KEK SRF gun #1. High gradient tests were done with dummy cathode plug, which was shaved out from bulk niobium and doesn't have the cathode mount structure. The cathode plug cleaning is important to

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achieve high gradient. Figure 3 shows the vertical test with and without high pressure rinsing (HPR) after mounting the dummy cathode plug. The peak surface electric field reached 75 MV/m and X-ray couldn't be observed with HPR. We understood it is important to ultra-clean the head of the dummy cathode plug up. However HPR should not apply to the transparent superconductor cathode substrate because it is very thin and delicate. We have to search other method for cleaning for example hydrogen cleaning or sputtering.

Table 1: KEK SRF gun #1 parameters

Parameter	Value
Beam energy	2 MeV
Project emittance	0.6 π mm. mrad
Project energy spread	0.09% (1.84 keV)
Peak electric field	41.9 MV/m
Peak magnetic field	95.2 mT
RF phase	55°
Geometrical factor	135.6 Ω
Target surface resistance	30 nΩ
Target Q value	4.5×10^9
Target cavity loss	8 W

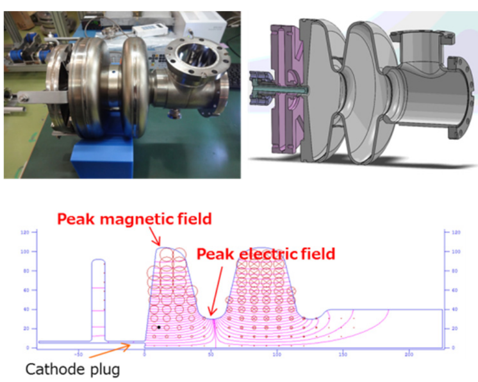

Figure 2: KEK SRF gun #1

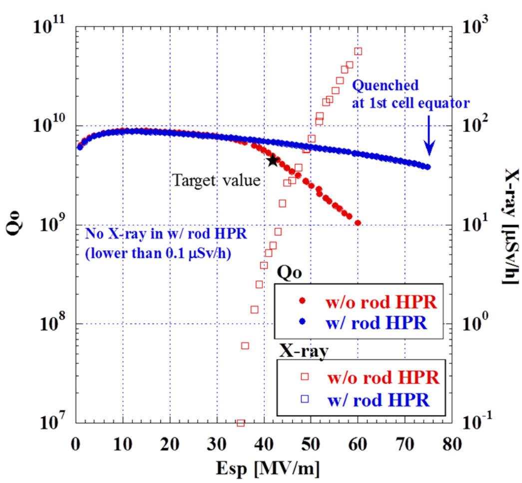

Figure 3: Vertical test results.

PHOTOCATHODE DEVELOPMENT

The practical performance of the photocathode using transparent superconductor was evaluated by measuring the quantum efficiency, initial emittance and critical DC magnetic field.

Deposition and Quantum Efficiency

The photocathode evaporation chamber has SAES cesium, SAES potassium and bulk antimony evaporation sources. The photocathode substrates are heated and cleaned at 500 ºC, 3 hours before deposition. The photocathode temperature stays about 100 ºC during deposition. Excitation laser and xenon lamp can inject from front and back side of the photocathode. The chamber vacuum is 6×10^{-8}~1×10^{-7} Pa during the deposition. Base pressure is 1×10^{-8} Pa.

Typical evaporation procedure is following. First, deposit antimony 10 nm at 150 ºC. The thickness was measured by quartz crystal micro balance and transparent efficiency of 405 nm laser. Then, deposit potassium at 120 ºC until observing the maximum quantum efficiency. Finally, deposit caesium at 100 ºC until observing the maximum quantum efficiency. We achieved 7% quantum efficiency at 405 nm.

Figure 4 shows the quantum efficiency changes during the cooling to 6.7K. The photocathode substrate is $SiTiO_3$. K_2CsSb deposition procedure discussed above. The initial quantum efficiency is 10% with 405 nm laser at room temperature. The cooling chamber pressure is 3.6×10^{-8} Pa. This quantum efficiency is not reversible manner with temperature. We supposed residual gas absorbed photocathode surface and increase the surface work function. Further study of photocathode performance at cryogenic temperatures and ways to improve this performance is essential for the photocathode development.

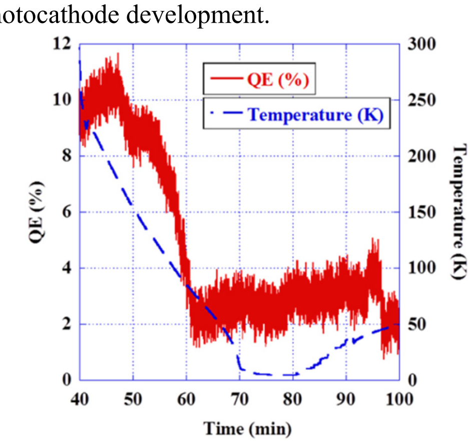

Figure 4: Changes of quantum efficiency during cooling down.

Initial Emittance

The initial emittance is measured based on the LBNL method [6]. The laser spot size is smaller than the beam size at far from parallel plate DC gun. Emittance can be measured from the beam divergent angle.

Figure 5 shows the initial emittance at room temperature. The energy threshold of the photocathode is 1.85±0.15e V.

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The initial emittance with 405 nm is larger than with 532 nm laser. It agrees with the theoretical value. Figure 6 shows the temperature dependence of the initial emittance with 405 nm laser. The measurement temperature is room temperature and 6.7K. Quantum efficiency decreased during the cooling down. 532 nm laser couldn't emit enough electrons. 6.7 K initial emittance is smaller than room temperature. It is not enough to prove the temperature dependence because the threshold energy is not measured. Considering the emittance difference between room temperature and 6.7K is 0.02 µrad /mm by the theory. There is no contradiction in the measurement result.

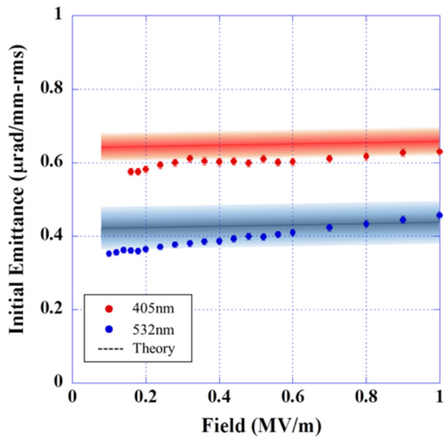

Figure 5: Initial emittance measured with 405 nm and 532 nm laser.

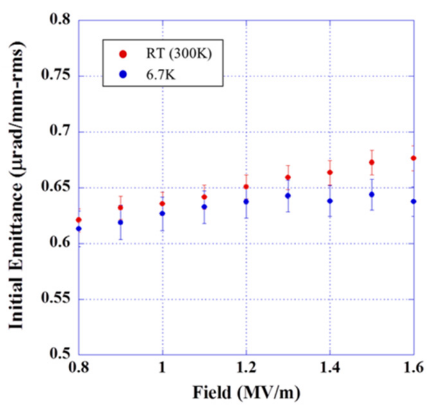

Figure 6: Temperature dependence of the initial emittance with 405 nm

Critical DC Magnetic Field

Both the transparent superconductor and bi-alkali photocathode use the alkali metal. We are concerned the change of superconducting properties after K_2CsSb deposition. Figures 7 and 8 show the critical temperature and lower critical magnetic field before and after K_2CsSb deposition. They were measured by magnetic property measurement system (MPMS-7) (Quantum design, Inc.). The transition temperature is 11.4K. The lower critical temperature is 9.5 mT at 2K. Although they are slightly decreased than before deposition, they satisfy the use condition in KEK-SRF gun usage.

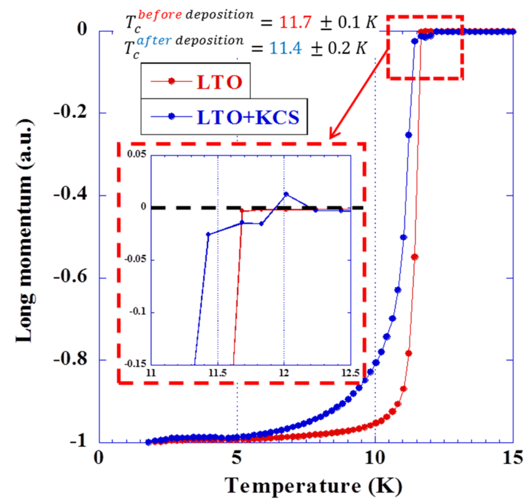

Figure 7:Transition temperature

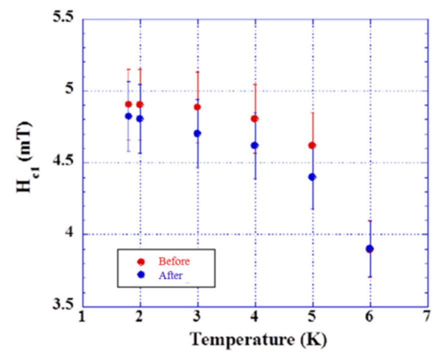

Figure 8: Lower critical magnetic field

SUMMARY AND FUTURE PLANS

KEK starts SRF gun development using the transparent superconductor. The gun cavity and photocathode have been developed individually. The surface peak electric field reached 75 MV/m which is about twice the target value. Although the photocathode critical magnetic field is enough higher than target value, it has many problems for practical use. Further study at cryogenic temperatures and ways to improve this performance is essential for SRF gun development. We will develop the KEK SRF gun #2 and new cathode deposition chamber for evaluating the photocathode in RF condition and beam parameter.

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