A LOW EMITTANCE DC ELECTRON GUN USING SINGLE CRYSTAL CATHODE OF LaB_6

K. Kasamsook[1], M. Kawai, K. Akiyama, F. Hinode, T. Muto, K. Nanbu, T. Tanaka, M. Yasuda, H. Hama
Laboratory of Nuclear Science, Tohoku University,
1-2-1 Mikamine, Taihaku-ku, Sendai 982-0826, Japan

Abstract

Development of an electron gun capable of producing low emittance is in the interests of further appliocations of high brightness electron beam. A prominent point of this DC gun is that operaion high voltage is very low because of the small size of cathode and a short distance between the cathode and the anode. A pulsed high voltage of 50 kV is supplied, and pulse duration is variable from 1 to 5 μsec. The design details and present status are reported.

INTRODUCTION

The DC electron gun project at LNS to generate a high brightness gun with low emittance and long operational lifetime has been developped. The low emittance DC electron gun is also supposed to be useful for applications such as Smith-Purcell FEL [1]. We have chosen single crystal LaB_6 as the thermionic cathode because it can provide higher current density with good homogeneity in electron emission. In addition, a floating bias voltage can be applied between the cathode and the wehnelt.

Some numerical calculations have been performed. The normalized emittance is expected to be less than 5 π mm mrad. A state of the art electron source will possibly open new scientific opportunities in many fields.

THE LOW EMITTANCE DC ELECTRON GUN

We have constructed a low emittance DC electron gun. The schematic diagram of DC electron gun system is shown in Fig.1. The design parameters and the drawing of the low emittance DC electron gun are shown in Table 1 and Fig.2, respectively. In spite of such low voltage, the emittance can be reduced to very small because of a very short distance between the cathode and the anode. In order to produce low emittance beam, the cathode size should be small, so that the higher current density is required. Such high current density can be realized by some cathode materials such as single crystal LaB_6 [2] or CeB_6 [3]. The position of cathode is very sensitive for the emittance growth to the mechanical problem to precisely adjust the cathode position. So we need special bias voltage to manipulate the electric field around the cathode surface.

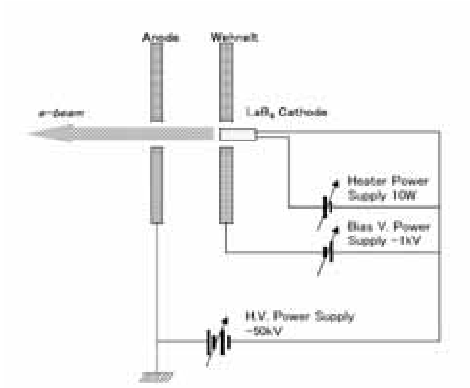

Figure 1: The schematic diagram of DC gun system.

Table 1: Design parameters of electron gun.

Beam energy	50 keV (Max.)
Peak current	>300 mA
Pulse width (FWHM)	1-5 μsec
Repetition rate	300 pps (Max.)
Normalized emittance	<10 π mm mrad.
Normalized thermal emittance	0.25 π mm mrad*. *theoretical
Cathode diameter	1.75 mm.

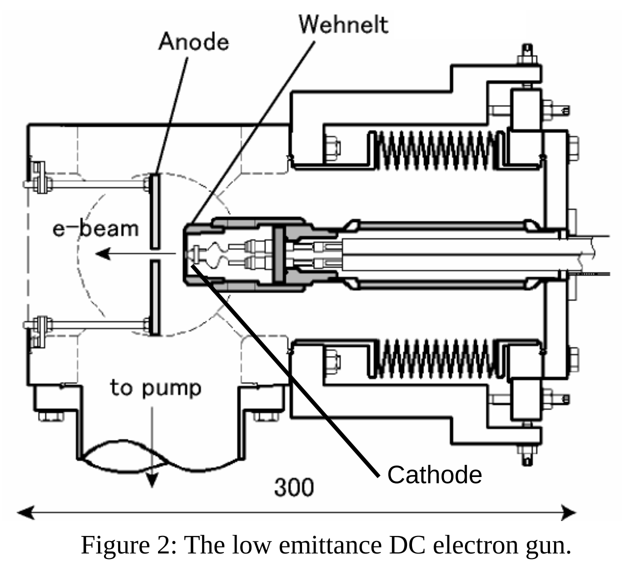

Figure 2: The low emittance DC electron gun.

[1]kasam@lns.tohoku.ac.jp

LaB_6 cathode

The normalized rms thermal emittance of electrons emitted from a hot cathode is described by equation (1):

$$\varepsilon_{\mathrm{n,rms}} = \frac{r_c}{2}\sqrt{\frac{k_B T}{m_o c^2}} \quad , \tag{1}$$

where r_C is the cathode radius, k_B is Boltzman's constant, m_0 is electron rest mass and T is the cathode absolute temperature. From the above relation, in order to obtain the small emittance less than 1 π mm mrad required for an example, the X-ray FEL application, the diameter of the cathode must be in the range of a few mm. On the other hand, high emission density (~12 A/cm^2) is required to produce a several hundred miliampere peak current from the small surface. The LaB_6 or CeB_6 can emit such an intense current over long lifetimes. A single crystal is preferable for obtaining low emittance because of its extremely flat surface with low porosity after surface material evaporation. The emission density is more uniform because the crystal orientation is the same over the whole surface. In recent years, single crystal LaB_6 cathodes are widely used for scanning electron microscope (SEM) and superior stability has been demonstrated. So, we decided to use a single-crystal LaB_6 cathode with a flat crystal surface shown in Fig.3. The diameter of our LaB_6 cathode is 1.75 mm. The 300 mA peak current will be produced when the cathode is heated to ~1900 K at vacuum level of 10^{-8} torr or better. The theoretical thermal normalized emittance is 0.25 π mm mrad.

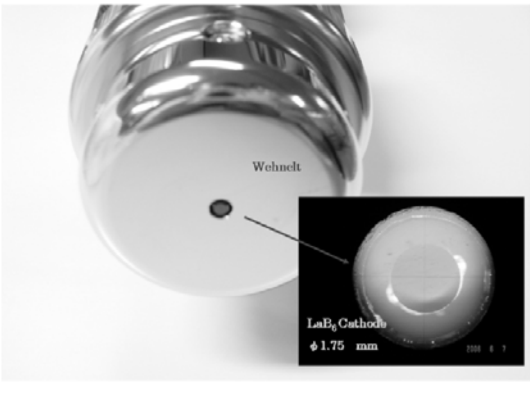

Figure 3: The assembly of single-crystal LaB_6 cathode.

High-voltage power supply

The high-voltage power supply was tested by loading at an electron gun system to generate an electron beam.The beam current was measured by the Faraday plate. The cathode was heated up to ~1800 K and the current, 200 mA, was measured in the test chamber by applying 10 W of heater power. So, one of reasons to achieve peak current, 300 mA, is that we have to increase the absolute temperature of the cathode. Up to now, the cathode has been operated for 700 hours without failure. Fig. 4 shows the measurement waveform of the accelerating voltage and beam current and Fig.5 shows the waveform of the gun voltage and beam current respectively.

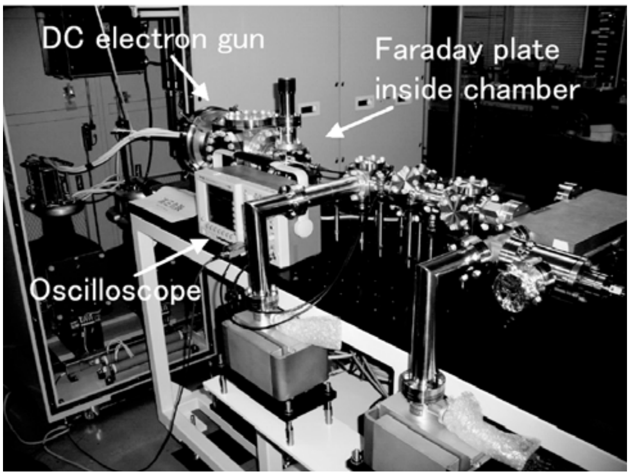

Figure 4: The measurement of gun voltage and beam current.

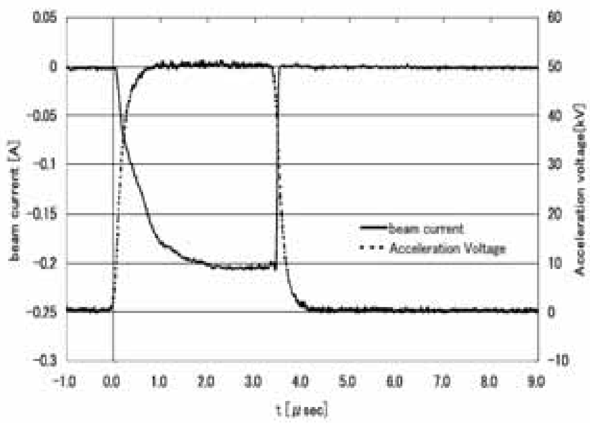

Figure 5: The waveform of accelerating voltage and beam current.

Numerical calculation results

We performed a computer simulation using EGUN code [4] for 50 keV, 300 mA beam current and 15 mm cathode-anode distance, 0.1 mm mesh size in simple model. As shown in Fig.6, the beam trajectories diverge too much including the emittance growth due to space charge, which would result in a rapid increase in beam spot size. In the case of small cathode size, the electric field near the cathode surface is very sensitive to the emittance growth, which means the mechanical positioning of the cathode is very important. So we need special bias voltage between cathode and wehnelt to manipulate the electric field around cathode surface.

The normalize emittance (4ε) at 1 cm from anode exit was shown small value (3.27 π mm mrad). Fig.7 and Fig.8 show the phase space distribution and the macro-particle distribution at the position 1 cm from the anode exit. However, the non physical distribution of macro-particle was existed. So, the mesh size around cathode surface should be smaller.

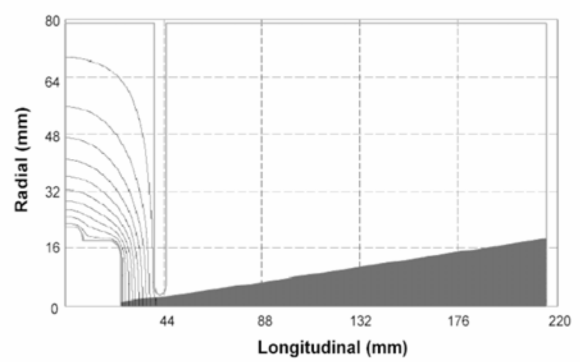

Figure 6: Extraction of an electron beam of 300 mA in a DC electron gun according to a simulation with EGUN.

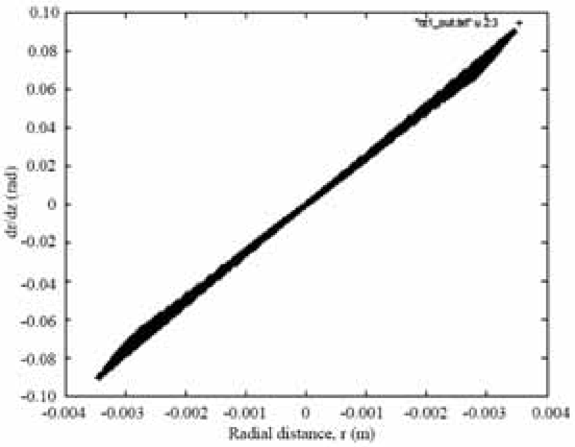

Figure 7: The phase space distribution at 1 cm from the anode exit according to a simulation with EGUN.

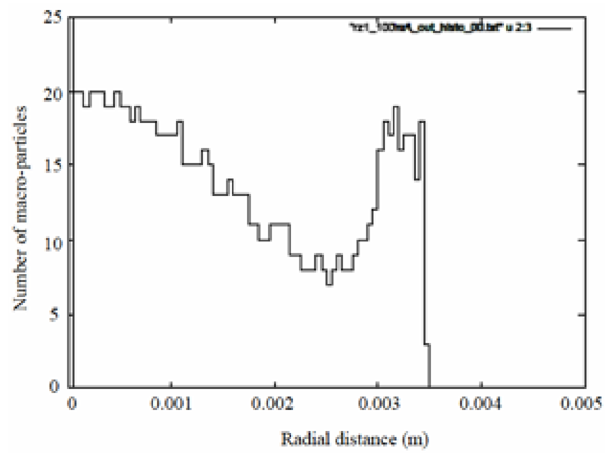

Figure 8: The macro-particle distribution at 1 cm from the anode exit according to a simulation with EGUN.

SUMMARY

Presently the DC gun has been examined on a test stand, and characteristics of the extracted beam from the gun are measured. The numerical calculation has also been performed using EGUN code. The results was shown the diverse beam along the longitudinal direction, so a series of solenoids is required to constrain these electrons and compensate for space charge effect. Nevertheless , the mesh size of the code must be reduce because the cathode is very small, and we should compare with other codes, paralleling to cross examine the experimental result. This paper reports on the commissioning of the test stand and a present measurement result.

ACKNOWLEDGEMENT

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REFERENCES

[1] K. Kim et al., Nucl. Instr. And Meth. A 475 (2001) 158.
[2] H. Kobayashi et al., Emittance Mearsurement for High-Brightness Electron Guns, 1992 Linear Accelerator Conf., Ottawa, Canada, August 1992
[3] K. Togawa et al.,"CeB_6 Electron Gun for the Soft X-ray FEL Project at Spring-8",FEL2003, Tsukuba, Japan, September 2003
[4] W.B. Herrmannsfeldt, EGUN-An Electron Optics and Gun Design Program", SLAC Report 331, Oct.1988