# High Current Density Electron Gun with a $LaB_6$ Thermionic Cathode

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## Abstract

To develop a high current electron gun for the induction linac, a small prototype of a Pierce-type electron gun using a planar 12 mm-diameter lanthanum hexaboride as an electron emitter has been made. The basic properties of the gun are under investigation and preliminary results are presented. The gun has been operated up to 21kV, obtaining current of 5.5A with 250 nsec width at 1,650℃ in the space-charge-limited region. The cathode is heated by electron bombardment and radiation from a tungsten heater. The maximum temperature of the cathode reaches 1,690℃ when the total heating power comes up to 590W.

## 1. Introduction

A single-stage microwave free electron laser (FEL) which is driven by the induction linac energized by magnetic compressors1) is constructed at KEK. The purpose is to develop a high power microwave source for a future linear collider.2) The large-area cathode used at KEK is a field emission (cold) type and emits an electron beam current of two or three kA. Electron beams have been generated using cold cathodes, such as metal cathodes, velvet cathodes, graphite wool cathodes. The cold cathode has a short life of several hundred shots because of an evaporation of the cathode surface. A transmitted beam current of the beamline installed in a downstream of the induction linac fluctuates in every shot. The reason is thought of variation of the beam emittance. These phenomena aren't preferable for the investigation of the FEL performance. Also, these cathodes aren't suitable for high repetition pulsed devices. Conventional thermionic dispenser cathodes are capable of producing high repetition pulsed beams, but are limited to application in devices where ultra-high vacuum below $10^{-8}$ Torr is maintained. The current densities of conventional cathodes are limited up to ~5A/cm$^2$. The cathodes are not selected for use in our experiment because it can't be used in low pressure. To overcome the defects on the above cathodes, the high current gun with a reliable thermionic cathode is developed at KEK since 1991. Lanthanum hexa-boride ($LaB_6$) is used as a cathode material because of high density and resistance to chemical poisoning.

In this paper, we discuss on the small prototype of electron gun assembly heated to high temperature and on the cathode heating system using the electron bombardment and radiation from the heater. We present preliminary results on the high voltage operation of the gun with the thermionic $LaB_6$ cathode.

## 2. Electron gun assembly

The Piece-type electron gun consists of a planar cathode and an anode with an extraction hole. The gun was designed with the aid of the EGUN program3). The perveance of the gun was determined to 1.4 x $10^{-6}$ A/V$^{3/2}$, taking account into the required current over 1000A when, in the near future, an ultra-high voltage gun of practical use would be installed in the induction linac. According to the basic properties of the $LaB_6$ cathode,4)~8) the prototype gun was designed as shown in the parameter lists of the following Table.

Table Parameters of the gun with a $LaB_6$ cathode

| | |
|---|---|
| Cathode temperature | 1900° K |
| Current density | 10 A/cm$^2$ |
| Anode voltage | 40 kV |
| Beam current | 11.1 A |
| Emittance | 7.2 cm*mrad |
| Perveance | 1.4 μperv. |
| Pulse width | 250 nsec. |
| Repetition rate | 20 Hz |

An assembly drawing of the gun is shown in Fig.1. The gun is mounted on a 46mm diameter, 5mm thick boron nitride (BN) base plate. The cathode is made of a sintered $LaB_6$ disk with 12mm diameter and 3mm thickness. The $LaB_6$ cathode is set in a graphite cup of 20mm diameter because of the same coefficient of thermal expansion and no reaction with refractory metals such as tungsten, molybdenum or tantalum at elevated temperatures.4) It is mounted on a molybdenum holder which serves for a focusing electrode. Further the holder is mounted on a 56mm diameter, 0.5mm wall tantalum tube. The tip of this tube is drawn by a spinning to form a Wehnelt electrode. The tube contains the heating tungsten filament and heat shield. The spiral bombardment filament is made of 0.7mm diameter pure tungsten wire. The anode is made of molybdenum and mounted on the outer vacuum chamber. Waters cooling jackets are fitted up to the chamber which is heated by radiation from inner filament and cathode.

To confine a heat radiated from the filament, a radial and axial heat shields are set up inside the tantalum tube. They combine to enclose the filament in a small pillbox bounded on one end by the axial heat shield and on the other by the graphite cup which mounts the $LaB_6$ cathode. The radial shield is five-fold wound by a thin sheet with many dimples. The dimples keep the gap between the neighboring sheets for thermal isolation. The axial shield is stacked with six thin disks with the same dimples. Both shields are 0.1mm thick and made of tantalum.

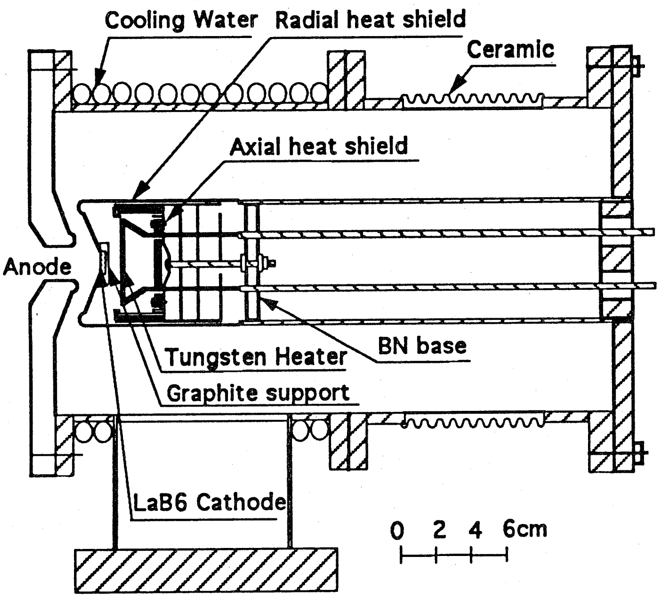

Fig.1 Gun assembly with the bombardment heated $LaB_6$ cathode.

## 3. Cathode heating system

The $LaB_6$ cathode is heated by the bombardment and radiation method. Fig.2 shows a block diagram of the heating system. The tungsten filament is directly heated by a DC current to a temperature where it can source a maximum electron beam current of 350mA. The filament is negatively biased with respect to the cathode by bombardment voltage of 800~1200V. The DC power supply for the bombardment causes a temperature-limited electron beam to bombard the cathode. To protect the DC power supplies, blocking coils between the DC power supplies and a high-voltage pulse power supply electrically isolate pulses from the high-voltage power supply.

The amount of bombardment current can be directly controlled by the electrical heating power because of a temperature-limited bombardment beam. Radiated power from the cathode is also a heating power to the filament. This power causes an increase in the filament temperature, so the bombardment voltage decreases as we use the power supply to be a constant current. The decreased bombardment voltage results in decrease in the cathode temperature and the power radiated back to the filament. On the other hand, when the power supply for the filament works as a constant voltage, the bombardment current increases. The increased current results in increase in the cathode temperature and the power radiated back. Thus, in a temperature-limited region, it forms a positive feedback loop between the cathode and the filament.9)

To eliminate these difficulties, we have used the power supply that is controlled to a constant power for the filament. When the filament is heated by the radiated power from the cathode, a resistance of the filament increases, so the filament consuming power rises. As the power supply is controlled to the constant power, it maintains the filament at constant temperature.

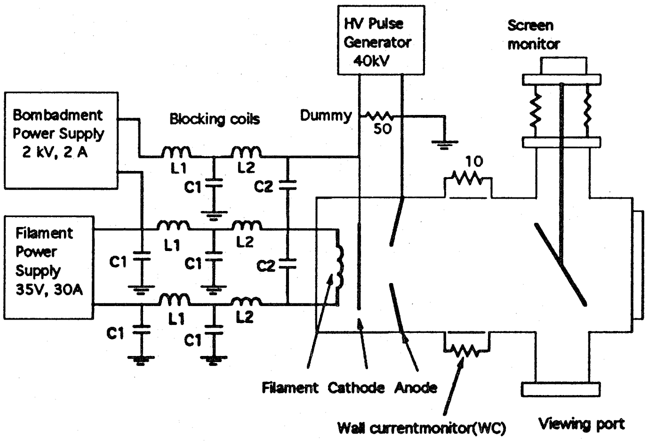

Fig.2 Bombardment and radiation heating system.

## 4. Cathode heating and high-voltage pulsing results

The $LaB_6$ cathode is heated by a bombardment and radiation as stated before. Fig.3 shows the result of the cathode temperature measurements.

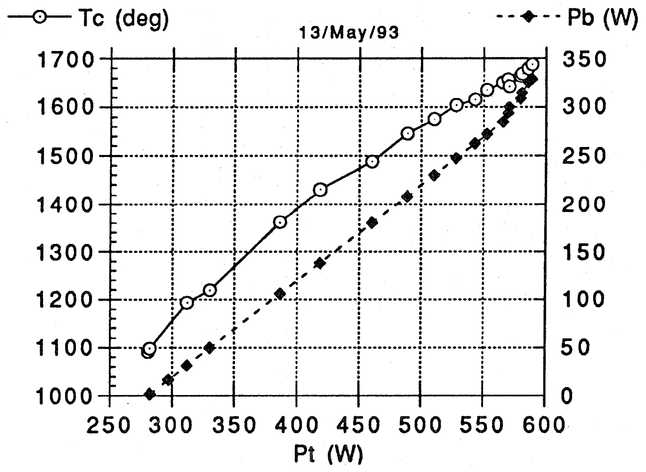

Fig.3 Total electrical heating power versus cathode temperature.

The cathode temperatures are measured by an infrared radiation thermometer (0.95μ) calibrated by an optical pyrometer. The cathode temperature is raised up to 1,100℃ by only radiation when the filament power reaches to 280W. When the bombardment power plus the filament power fixed to 280W comes up to 590W, the cathode temperature attains to the maximum value of 1,690℃

Fig.4 shows high-voltage pulsing results of the electron gun. The gun has been operated with voltage pulses up to 21kV and cathode temperatures between 1,450°C and 1,650°C. The high-voltage pulse power supply is a pulse-forming line (PFL) type with a single thyratron switch.[10] A coaxial 20mm diameter cable with 25m length is used as the PFL.

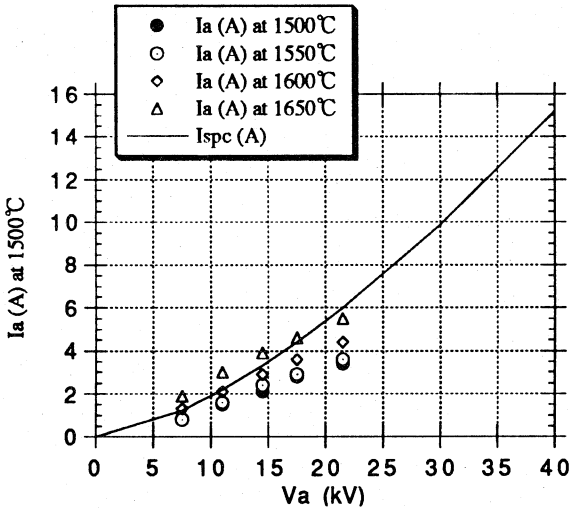

Fig. 4 Measured values of the cathode current as a function of voltages for the cathode temperatures.

The beam current is measured by a wall current monitor (WC) placed at a down-stream of the anode. The obtained maximum current is a 5.5A with a width of 250 nsec at 1,650℃ in the space-charge-limited region. The solid line in Fig.4 represents the space-charge limited current calculated by the Child-Lagmuir equation. A photograph of the beam current is shown in Fig.5. The lower trace represents an output of the WC. The noise level is below ± 0.3A. The upper trace represents a current of the 50Ω dummy load. The base pressure of the gun is around 9 x $10^{-8}$ Torr and increases as the cathode temperature increases. The measurements have been made in the range of vacuum pressure $10^{-7}$~ $10^{-6}$ Torr.

The above data are preliminary one's and we have to measure over a wide range of the cathode temperatures and pulse voltages.

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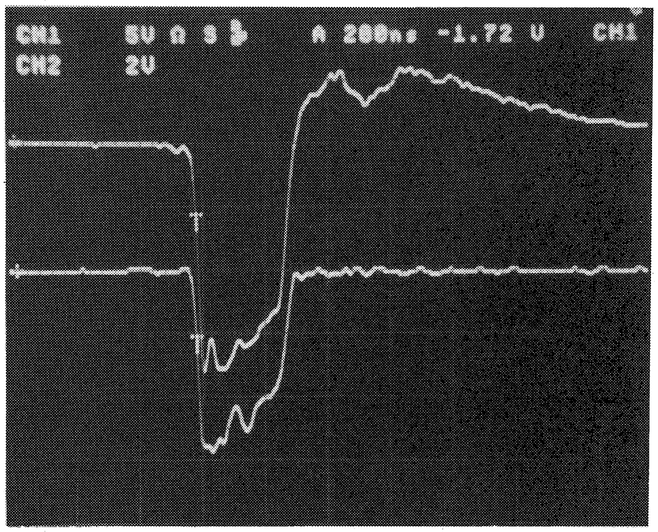

Fig.5 Photograph of the beam current which is measured with the WC monitor. The lower trace shows the beam current at 21kV.

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