EMITTANCE MEASUREMENT FOR HIGH-BRIGHTNESS ELECTRON GUNS

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Abstract

An emittance measurement system based on a high-precision pepper-pot technique has been developed for electron-guns with low emittance of around πmm-mrad. Electron guns with a 1 mmϕ cathode, the material of which is impregnated tungsten or single-crystal lanthanum hexaboride $(La_{1-x}Ce_x)B_6$, have been developed. The performance has been evaluated by putting stress on cathode roughness, which gives rise to an angular divergence, according to the precise emittance measurement system. A new type of cathode holder, which is a modified version of the so-called Vogel type, was developed and the beam uniformity has been improved.

Introduction

Both the generation of a small-emittance beam and its acceleration without emittance growth (future themes at the Test Linac[1]) of the KEK Photon Factory) are crucial for advanced applications of linear accelerators, such as a free-electron laser. Emittance growth during transport and acceleration and its prevention have been the subjects of extensive studies.[2][3] An electron gun with a small emittance, which can be used as a reference beam generator, and a very precise emittance monitor are the key components in such studies.

The thermal limit of the normalized rms emittance of a cathode with a radius of r_c at an absolute temperature of T is given by

$$\varepsilon_n = 2\pi r_c (kT/m_0c^2)^{1/2} \qquad (1)$$

A comparison between ε_n and the measured value is of interest.

Lau has evaluated the emittance determined by the cathode roughness regarding both temperature-limited and space-charge-limited emission.[4] Loschialpo et al. has measured the emittance of a large area polycrystal LaB_6 cathode with protrusions of two to three microns height, finding a greater emittance than the thermal limit.[5] Few studies, as far as we know, have been carried out concerning the roughness of various cathodes.

A dispenser cathode with a long history has made great progress during recent years. A current density of even $100A/cm^2$ (but with a comparatively short lifetime) is commercially available. A dispenser cathode with craters, but no protrusions on the surface, is available. A single-crystal lanthanum hexaboride$(La_{1-x}Ce_xB_6)$ cathode with a high crystal quality has recently been developed.[6] Part of the surface of the single crystal is extremely flat. These new cathode materials have different surface conditions from that of polycrystal LaB_6 and factors which give rise to an angular divergence have stimulated us to investigate electron guns with these materials using a precise pepper-pot method.

Emittance Measurement Technique

Details concerning the emittance measurement system used in these experiments will be described elsewhere.[7] A schematic block diagram is given in Fig. 1, and outlines of the measurement system are described. The pinholes of the pepper-pot mask are 30 μm in diameter and opened at intervals of 200 μm radially or at intervals of 300 μm with a grid pattern. A plastic scintillator with a fast temporal response and with a high spatial resolution due to the 10 μm thinness is employed to measure the images of beamlets cut out by such small pinholes. A microscope used to observe small luminous 300- to 700-μm spots on the plastic scintillator and an image intensifier with a high-speed shutter (minimum time of 3 ns) to measure the beam images at the flat top of the beam pulse and a CCD camera are mounted on a precise movable platform. The magnified spot images can be measured one by one by scanning the optical system. A magnetic field, if desired, can be applied between the pepper-pot and the scintillator to confirm the energy of electrons comprising the spots. The features of this emittance measurement system are summarized in Table 1.
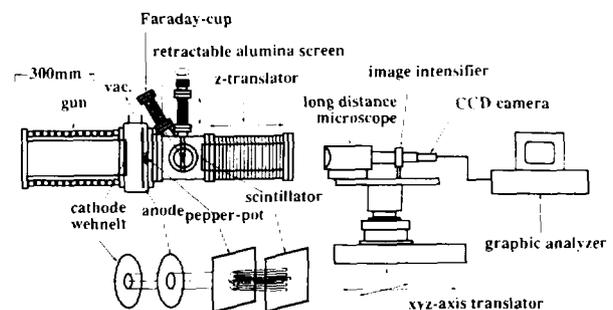

Fig. 1. Emittance measurement system

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TABLE-1. Features of Emittance Measurement System

Pepper-pot mask
Ti foil 20 μ m thickness, pinhole 30 μ m diameter
200 μ m radially or 300 μ m grid pattren
Scintillator
10 μ m thickness, luminance peak 375nm,
rise time : 350ps, decay time : 1.6ns
Optical system
long distance microscope(resolution 3 μ m)
image intensifier(minimum shutter time of 3ns)
mounted on xyz movable platform

Cathode heating method

In an electron gun a space between the heated cathode and the wehnelt electrode at normal temperature is necessary for thermal insulation. The cathode is held in a so-called Vogel-type[8] holder; the vicinity of the cathode is shown in Fig.2(a)-upper. At the beginning of the gun design we wanted to make the space as small as possible, thus adopting the 0.1 mm, just one mesh size in a calculation in which the area between the cathode and the anode is divided into four.[1] The current-density distribution measured by the pepper-pot system described above was very different from that predicted by the EGUN code,[9] and the small space seemed to greatly deflect the beam trajectory. Accordingly, the electron trajectories in the very vicinity of the cathode were calculated based on a small mesh size of 0.025 mm. When the cathode is held at the same position with the wehnelt electrode longitudinally (both surfaces in one plane) only the beam from the edge of the cathode is deflected by the electric field distorted by the space. The beam trajectories, however, are greatly affected by a longitudinal cathode shift with respect to the wehnelt electrode position. Only a 0.1 mm shift gives rise to an angular divergence extending over the entire cathode; the beam trajectories and phase space of the beam in the very vicinity of the cathode are shown in Figs.2(a)-middle and -lower respectively. We developed a modified Vogel-type cathode holder in which the cathode is surrounded by a carbon heater so as to avoid space effects (Fig.2(b)-upper). The relative position of the cathode and the carbon in this type can be easily adjusted to make one plane. The influence of the space between the carbon and the wehnelt electrode as well as the relative longitudinal position between the carbon with the cathode and the wehnelt electrode becomes negligibly small. Even if the cathode is attached behind the wehnelt electrode by 0.2 mm, the beam trajectories are not distorted; Fig.2(b)-middle shows this situation with the phase space of the beam in Fig.2(b)-lower. When the cathode without carbon was attached behind the wehnelt electrode, two pinhole images appeared through one pinhole. Typical pinhole images at the beam edge without and with the carbon surrounding the cathode are shown in Figs. 3(a) and (b), respectively.
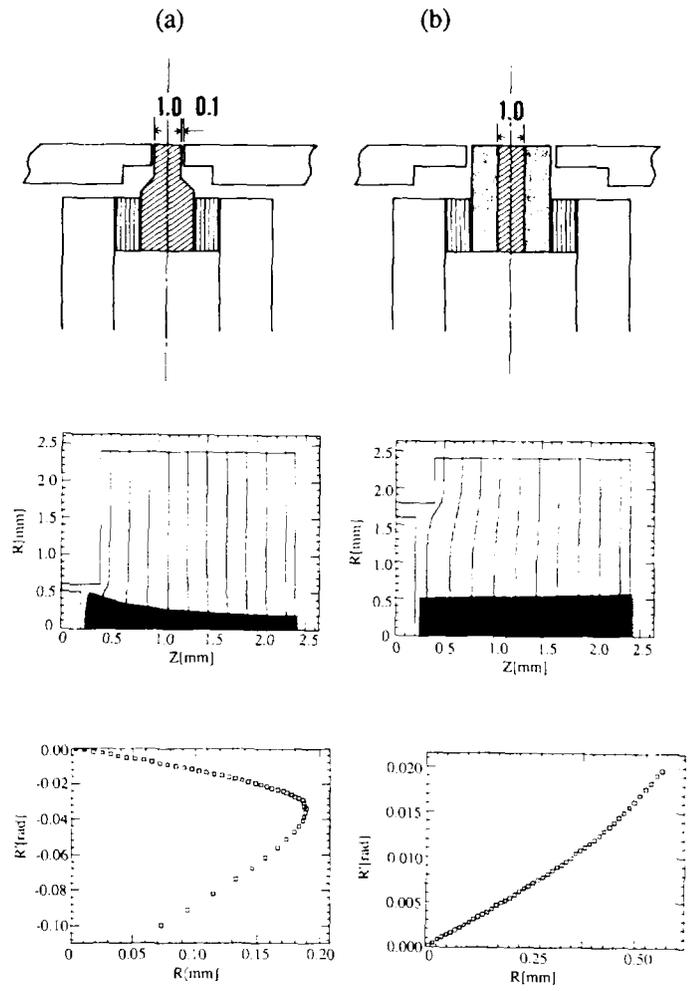

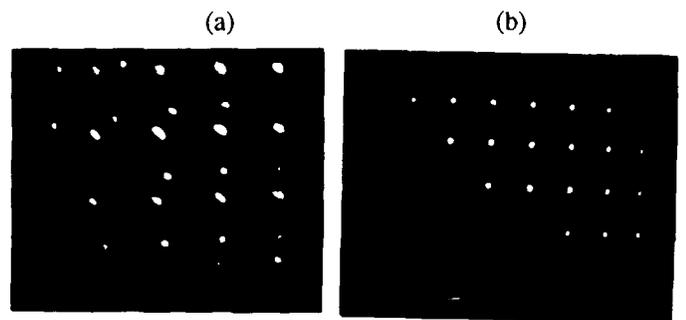Fig.2 Cathode holder and beam trajectory and phase space without(a) and with(b) the surrounding carbon.

Fig. 3 Typical example of images at beam edge without(a) and with(b) the surrounding carbon

Emittance of the Dispenser and LaB_6 Cathodes

It is pointed out that the roughness of cathode surface is one of the important conditions which determine the brightness. Lau has evaluated the emittance determined by the cathode roughness for both temperature-limited and space-charge-limited emission, as described above. Distorted pepper-pot images due to protrusions of cathodes were often observed in our experiments. We thought that the surface(100) of the single

crystal LaB_6 is extremely flat compared with those of polycrystal LaB_6 and of dispenser cathodes. This is of interest from the viewpoint of cathode roughness. Emittance measurements of electron guns with the dispenser-type cathode and with single-crystal LaB_6 have been carried out.

The single-crystal $(La_{1-x}Ce_x)B_6$ prepared by the RF-heating floating zone method[6] is mounted in the modified Vogel-type cathode holder described above. In the case of single-crystal LaB_6, protrusions of several microns height tend to remain after electro-discharge machining; a fresh surface after machining and very large pepper-pot images at this roughness arc shown in figs.4(a) and (b), respectively. However, by keeping the cathode at 1600 °C, the surface became gradually flat due to evaporation, and the pepper-pot images became small with the surface condition. Then, we prepared a polished single-crystal LaB_6 cathode to obtain a very flat surface. The surface of the cathode after 72 hours use and the pepper-pot images at this stage are shown in figs.5(a) and (b), respectively. A current of 496 mA (density of $57.3 A/cm^2$) and a brightness of 5.7×10^{10} $A/m^2 rad^2$ ($\varepsilon_n = 0.94 \pi mm$-mrad) were obtained at 1580°C.

(a)   (b)
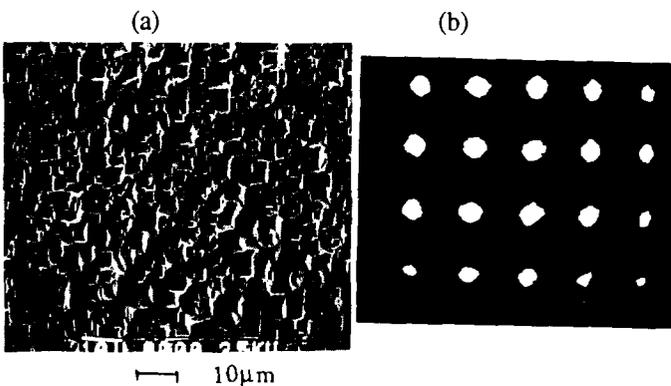
⊢——⊣ 10μm

Fig. 4 Surface of single-crystal just after machining(a) and pepper-pot images(b).

(a)   (b)

⊢——⊣ 10μm
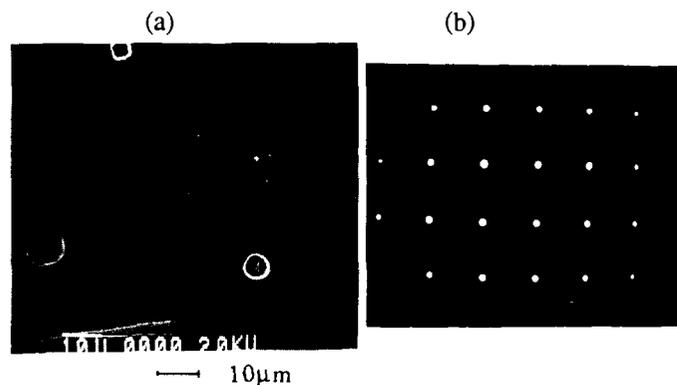
Fig. 5 Surface of polished single-crystal LaB_6(a) and pepper-pot images(b).

We have prepared two different types of dispenser cathodes with and without polishing after machining. In these experiments, cathodes coated with an iridium are used under the condition of a temperature-limited region. Some cathodes without polishing showed rough local regions; a greatly distorted images were observed. In the case of dispenser cathodes with polishing, the craters among tungsten-grains are

several microns in size and are spread over the cathode. According to very rough estimations by the EGUN code, craters with a 6 μm diameter and a 3 μm depth give rise to an angular distribution equivalent to the cathode temperature during operation in this condition; however, the protrusions with similar dimensions give a far larger angular velocity. The cause of the very distorted images for a cathode without polishing can be attributed to the protrusions. For polished cathodes, a current of 412 mA at the current density of $36.4 A/cm^2$ with a brightness of $3.5 \times 10^{10} A/m^2 rad^2$ ($\varepsilon_n = 1.1 \pi mm$-mrad) was obtained at 1080°C. The emittance values for both the dispenser cathode and the single-crystal LaB_6 are almost the same in these experiments. The difference, however, is that oval images are often observed for the dispenser cathode, in the contrast to circular images for the single-crystal LaB_6. Emittance of 95 percent beam has been used and error of ±20 percents is contained for these measurements.

Summary

A precise pepper-pot technique has been developed. Electron guns with a dispenser and LaB_6 cathode have been developed and their beam emittances measured. When protrusions of several microns in size are on the surface of the cathode, a clear spread of the pinhole image has been observed. A dispenser cathode with craters of several microns in size and single-crystal LaB_6 showed similar emittances in these measurements, though the intensity distribution of the pinhole-image for LaB_6 is somewhat different from that of dispenser cathode and this is the subject for future study. Modified Vogel-type cathode holder improved beam uniformity.

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