GRAPHITE HEATER OPTIMIZED FOR A LOW-EMITTANCE CeB_6 CATHODE

K. Togawa*, A. Higashiya, T. Shintake
RIKEN/SPring-8, 1-1-1 Kouto, Sayo, Hyogo 679-5148, Japan

Abstract

We developed a thermionic cathode assembly using a single-crystal CeB_6 emitter for the x-ray free electron laser project at SPring-8. The CeB_6 cathode has excellent emission properties, i.e., smooth surface, high emission density, uniform emission density, and high resistance to contamination. In order to heat the cathode up to the operational temperature as high as 1500°C, we developed a new-type of graphite heater. Using this heater, a 500 keV pulsed electron beam with more than 1 A peak current can be extracted from the small surface area (3 mm diameter). In this paper, we report on the design and properties of the graphite heater for the low-emittance CeB_6 cathode.

INTRODUCTION

X-ray free electron laser (FEL) is a very promising machine for analyses of atomic-scale structures such as single-biomolecule, researches of ultra-fast phenomena in various materials, etc. [1-3]. In the case of the x-ray FEL based on the self-amplified spontaneous emission, an electron gun is required to generate a low-emittance high-intensity electron beam. For the x-ray FEL project at SPring-8, we developed a 500 kV pulsed electron gun with a single-crystal CeB_6 thermionic cathode [4]. Rare-earth hexaboride cathodes, such as LaB_6 and CeB_6 are preferable to generate a low-emittance beam, however, the operational temperature is much higher than that of the conventional oxide cathode. In order to extract more than 1 A peak current from the small surface area (3 mm diameter), the CeB_6 cathode must be heated up to ~1500 °C. The heater temperature is inevitably much higher than that of the cathode. Therefore, it is necessary to use a strong heater for continuous long operation of the gun. We choose graphite as a heater material rather than the conventionally used tungsten or molybdenum. In this paper, we describe the design and properties of the graphite heater optimised for the low-emittance CeB_6 cathode.

ADVANTAGE OF GRAPHITE HEATER

Conventional cathode assemblies use a filament heater made of metal with a high melting point, like tungsten or molybdenum. However, we choose graphite as a heater material due to the following reasons. 1) Graphite also has a very high melting point (~3600°C), and it is mechanically and chemically stable even at high temperature. 2) As described in the next section, a cylindrical graphite heater can transmit the thermal power to the cathode effectively because it has wide radiation area. In the case of the conventional metallic filament, a thin wire is used to obtain enough electric resistance. If the cathode is heated by thermal radiation from the wire heater, the surface of the wire is not wide enough to transmit the thermal power. 3) Usually, tungsten grains recrystallize and their size enlarges at over 1500°C. As a result, the filament heater eventually becomes brittle. On the other hand, graphite is much stable even at high temperature, so that it can operate for long lifetime. 4) It is easy to control the heating power of graphite because its electric resistance does not change significantly as a function of the temperature. 5) Recently, high-purity graphite is available. Less outgases and particles are generated even at high temperature. The graphite is used for semiconductor epitaxy process in which very clean environment is required.

CYLINDRICAL STRUCTURE

A schematic diagram of the CeB_6 cathode assembly is shown in Fig. 1. The CeB_6 crystal is mounted in a graphite sleeve in order to reduce a beam halo from the cathode edge, which could cause damage to the undulator magnets. The cylindrical graphite heater is located to surround the sleeve. Thermal radiation from the inner

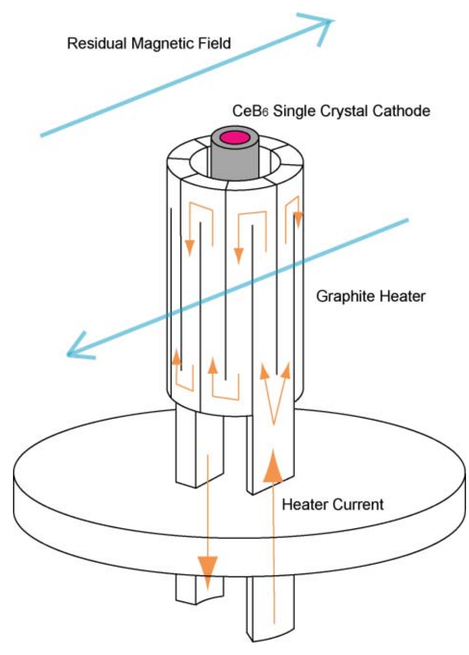

Figure 1: Schematic of cylindrical graphite heater.

* togawa@spring8.or.jp

1-4244-0917-9/07/$25.00

surface of the heater heats the sleeve directly, and the cathode is heated by the thermal conduction from the hot sleeve.

In order not to deteriorate the initial low-emittance of the beam, a longitudinal magnetic field penetrating into the cathode must be suppressed as low as possible. Therefore, a spiral-shaped heater can't be used. To solve this problem, we invented a new path pattern of heater current as shown in Fig. 1. The heater is divided into two paths. Each current flows into the first line in parallel with the beam axis, and it returns back in the neighboring line. The magnetic fields generated by a couple of these currents cancel out over the whole heater. Only the fields generated by the top and bottom paths can't be canceled out, however, the residual field direction is almost transverse to the beam axis. It is considered that the field does not affect the beam emittance so much.

The residual transverse magnetic field can deflect the beam trajectory. In the case that an AC power supply is used to generate the heater current, the deflection angle of the beam can be settled by synchronizing the beam pulse timing to the AC cycle.

HEATING PROPERTIES

We tested the cylindrical graphite heater in a cathode test chamber. Fig. 2 shows the heater operating at ~1300°C. The outer and inner diameters are 12 mm and 8 mm, respectively. The height of the cylinder is 15 mm.

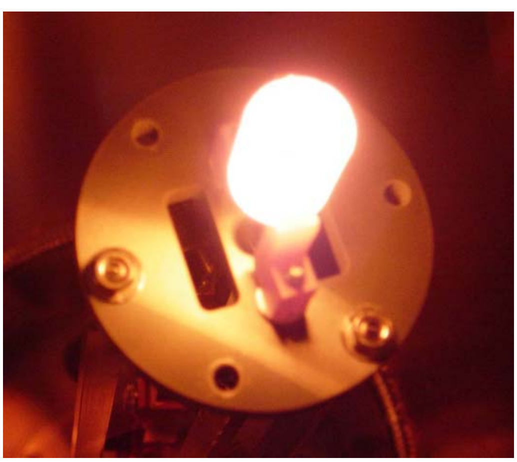

Figure 2: Operating graphite heater.

Heater Power

The relation between the electric power and the heater temperature was investigated. The heater temperature was measured by means of a radiation monitor [5]. In the measurement, the heater was surrounded by radiation shield made of tantalum to reduce a radiation power loss. As shown in Fig. 3, very high temperature of ~1600°C was achieved at fairly low heater power (~300 W). At such high temperature, the electric heater power is almost spent for radiation power loss, that is, the loss is proportional to T^4. The experimental data well represents the Stephan-Boltzmann law.

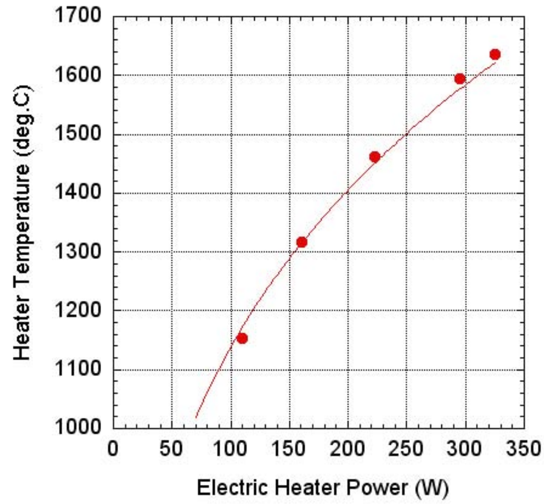

Figure 3: Heater temperature as a function of the electric heater power. Solid line is a fitting curve to the Stephan-Boltzmann law.

Heater Resistance

We measured the heater resistance as a function of the electric heater power (Fig. 4). Since graphite has negative thermal coefficient, the resistance decreases at a low electric power (low temperature). However, because the rate of the change is not high, we do not need a saturation transformer, which is used for the metallic filaments to suppress a rush current. At high temperature, the resistance is almost constant. Due to this property, it is easy to control of the cathode temperature.

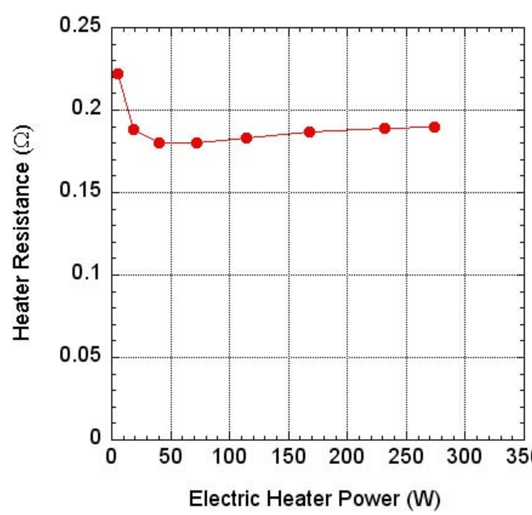

Figure 4: Heater resistance as a function of the heater power.

Vacuum

The vacuum pressure was 2×10^{-6} Pa at 1600°C when the pressure reached equilibrium. The base pressure of the chamber was 5×10^{-7} Pa. It shows that outgas is little enough for the operation of the CeB_6 cathode.

BEAM EMISSION PROPERTY

The CeB_6 cathode assembly with the developed cylindrical heater was installed in a gun chamber, and we measured the beam emission property. Fig. 5 shows beam current-voltage characteristics of the CeB_6 gun. We succeeded in generating a 500 kV pulsed beam with 1 A peak current and 3 μs width at cathode temperature of 1450°C. We also measured the beam emittance, and demonstrated that an extremely low emittance of 1.1π mm mrad (normalized, rms) could be generated from the CeB_6 cathode.

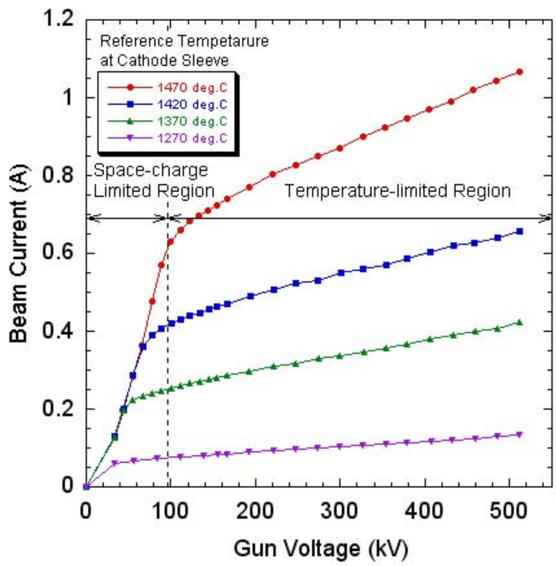

Figure 5: Beam current –voltage characteristics of the CeB_6 electron gun.

CONCLUSION

In conclusion, we developed a new-type of graphite heater optimised for a low-emittance CeB_6 cathode. The CeB_6 gun using this heater is being used for the SCSS (SPring-8 Compact SASE Source) test accelerator. In 2006, we succeeded in generating a FEL light with wavelength of 49 nm [6,7]. The graphite heater has been running for about two years without any failure.

ACKNOWLEDGEMENT

We would like to thank Mr. K. Onoe of RIKEN (present address is ULVAC TECHNO, Ltd.) for the help to the heater development. We also thank Dr. Y. Otake of RIKEN for preparing the synchronization system of the AC power supply for the cathode heater.

REFERENCES

[1] *LCLS Conceptual Design Report*, http://www-ssrl.slac.stanford.edu/lcls/cdr/

[2] *The Technical Design Report of the European XFEL*, http://xfel.desy.de/tdr/

[3] *SCSS XFEL Conceptual Design Report*, http://www-xfel.spring8.or.jp/SCSSCDR

[4] K. Togawa et al., Phys. Rev. ST Accel. Beams **10,** 020703 (2007).

[5] As calibration of the radiation monitor, we measured the temperature of a graphite sample located in the cylindrical heater by means of a W-Re thermocouple. The temperature measured by the thermocouple was systematically lower by 64°C than that measured by the radiation monitor. Since the thermocouple measured the sample temperature directly, we rely on the value of the thermocouple. Therefore, the temperature measured by the radiation monitor was corrected by –64°C.

[6] T. Shintake and SCSS Group, *Proceedings of EPAC 2006*, (Edinburgh, Scotland, 2006), pp. 2741-2743.

[7] H. Tanaka, et al., *Proceedings of FEL2006* (BESSY, Berlin, Germany, 2006), pp. 769–776.

