DEVELOPMENT OF BETTER QUANTUM EFFICIENCY AND LONG LIFETIME IRIDIUM CERIUM PHOTOCATHODE FOR HIGH CHARGE ELECTRON RF GUN*

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Abstract

We have been developing a new photocathode material as an electron source for the SuperKEKB electron linac. This injector is required to obtain a low emittance and high charge electron beams in order to achieve the highest luminosity all over the world. The required properties of a new photocathode are reasonably high quantum efficiency (QE > 10^{-4}) and high laser durability to achieve a long-term (> 1 year) accelerator operation.

We succeeded in developing an iridium cerium (Ir_5Ce) photocathode which has a reasonably high QE (~ 9.1×10^{-4} @213nm at room temperature) and long lifetime (> LaB_6). Furthermore, the QE of Ir_5Ce photocathode was increased to a maximum value of 2.70×10^{-3} by heating at 1006 °C. These great advantages of Ir_5Ce photocathode led to generate the electron beams with a maximum charge of 4.4 nC/bunch using a new-type RF gun at a test bench of KEK electron linac.

INTRODUCTION

A photocathode material is a key component to obtain the high charge electron beams using a photocathode RF gun. Generally, multi-alkali photocathodes (e.g. Cs_2Te, K_2CsSb) have been used as photocathode material in many facilities since they have low work function (< 3 eV) and high quantum efficiency (QE ~ 0.1). These photocathodes, however, are not suitable for SuperKEKB electron linac system since the lifetime of these photocathodes is not enough for a long-term continuous operation. On the other hand, the metallic photocathodes (e.g. Mg, Cu) have a long lifetime (< 1year) which is enough to operate a RF injector for a year without cathode maintenance. It is, however, difficult for these photocathodes to generate the high charge electron beams since they have too low QE.

We have tried to develop a new metal compound as a photocathode which has reasonably high quantum efficiency (> 10^4) and high laser durability to generate high charge electron beams for a long-term (> 1 year).

SELECT OF MATERIAL

The IrCe compound has a lot of good properties as a thermionic cathode. For example, it has a low work function of 2.57 eV at 1300 K [1] and a high melting point (1900 ~ 2250 °C [2]). For this reason, its thermionic cathode can generate one-order higher electrical current than that of a LaB_6 at the same temperature [3]. Another one is that the IrCe thermionic cathode has a two-order longer lifetime than that of LaB_6 thermionic cathode under the same condition [3]. Moreover, the IrCe compound shows a good resistance to poisoning and ion bombardment [4].

As can be seen above, several studies have been made on the IrCe thermionic cathode and proved it useful as a thermionic cathode. There has been, however, no study to use it as photocathode. We have tried to develop the IrCe compound by new methods of production and investigate the fundamental properties of the IrCe photocathode.

EXPERIMENTAL CONDITIONS

The QE was measured using the equipment shown in Figure 1. A fourth or fifth harmonic Nd:YAG laser was used to generate photoelectrons. At the beginning of the experiments the cathode has been treated by laser irradiation or heating at high temperature in order to clean the surface. In addition, the dependence of QE on cathode temperatures was measured.

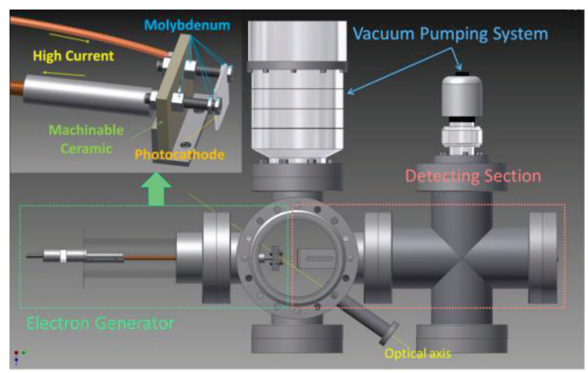

Figure 1: Equipment used to measure the quantum efficiency.

EXPERIMENTAL RESULTS

Laser Cleaning

Laser cleaning is a basic method of surface treatment in which the surface of a cathode is scanned with high-intensity laser pulses near the damage threshold to ablate the oxidized layer resulting in a pure cathode surface.

The conditions of laser cleaning are described below. Laser cleaning was performed using the fourth harmonic of a pulsed Nd:YAG laser. The scan area was 0.55 × 0.55 cm^2, and the number of shots of the laser pulse was 3.0×10^4 shots/cm^2. The energy density of the laser pulses was varied between 2.5 and 100 mJ/cm^2.

Figure 2 shows the dependence of the QE on the scanned energy density of cleaning laser. The QE of Ir_5Ce photocathode increased from ~3.51×10^{-6} for the un-scanned surface to ~1.02×10^{-4} for the surface scanned with 266 nm laser pulse at 10.0 mJ/cm^2.

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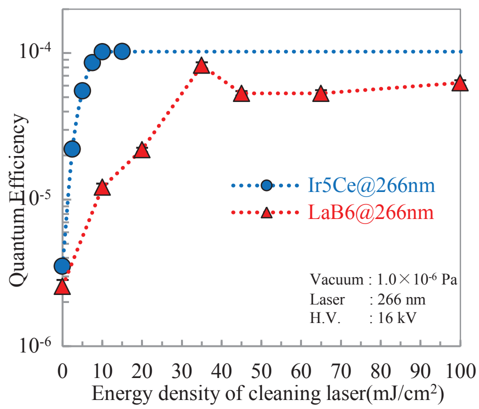

Figure 2: The QE as functions of the scanned energy density of cleaning laser.

In general, metallic photocathodes like magnesium require the irradiation of many laser shots (> 7.0×10^5 shots/cm^2) [5, 6] which have a high energy density (17 ~ 300 mJ/cm^2) [5, 6] to bring out the properties of maximum photoemission by laser cleaning. These results show that the surface of Ir_5Ce compound is more easily cleaned by laser pulses than other metal/metal compound photocathodes.

Heat Treatment

Heat treatment of a photocathode is also a basic method of surface treatment, in which the cathode is heated uniformly in order to evaporate the oxidized layers, resulting in a pure cathode surface. Heat treatment is well suited for the metals with a high melting point as Ir_5Ce to treat the surface.

Figure 3 shows the dependence of the QE of the Ir_5Ce on the heat-treatment temperatures. As can be seen from this figure, the effect of heat treatment greatly depends on the heating temperature. The effect of improving the QE suddenly began to appear when the heating temperature of photocathode exceeded about 600 $^{\circ}$C, and the QE became an almost constant value (QE ~1.54×10^{-4}) by heating it at approximately 900 $^{\circ}$C or more.

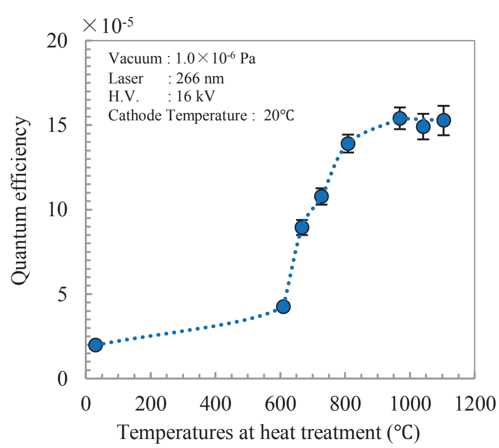

Figure 3: The QE of the Ir_5Ce photocathode as a function of the heat-treatment temperatures.

This result also shows that the heat treatment is more effective method to improve the QE of Ir_5Ce photocathode than the laser cleaning since improved QE after the heat treatment at 969 $^{\circ}$C was 1.5 times greater than that by laser cleaning.

The Dependence of Photoemission Properties of Ir_5Ce on Surface Temperature

In general, the QE of the metals with a high melting point increases with increasing cathode temperature at which significant thermionic emission does not occur. The quantum efficiency at 1000 $^{\circ}$C of LaB_6, for example, is three times greater than that at room temperature [7].

Figure 4 shows the dependence of the QE of the Ir_5Ce photocathode on the surface temperature. This figure shows that the QE of Ir_5Ce photocathode was increased by irradiating of a shorter-wavelength laser pulses, and increasing the cathode temperature during the measurements. The QE at 213 nm was six times greater than that at 266 nm at room temperature. Furthermore, the QE at 266 nm was increased to a maximum of 1.00×10^{-3} by increasing the cathode temperature; at 1004 $^{\circ}$C, the QE was 6.5 times greater than that at 266 nm at room temperature. The QE of Ir_5Ce photocathode was finally increased to 2.70×10^{-3} by irradiating laser pulses of 213 nm and heating the cathode surface at 1006 $^{\circ}$C.

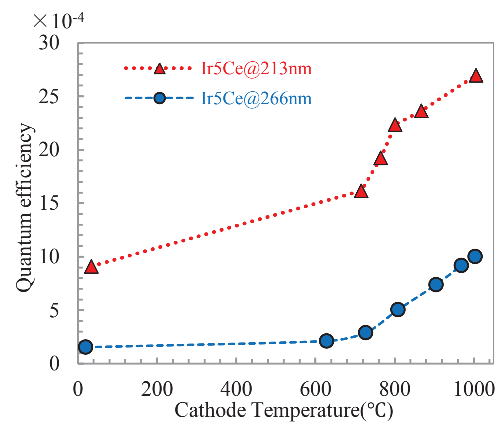

Figure 4: The QE of the Ir_5Ce photocathode as functions of the surface temperatures.

The Measurement of Lifetime

A new photocathode is required to have high durability against continuous irradiation of high-power laser pulses and long-term continuity of a good photoemission property under a reasonably low vacuum condition (10^{-6} ~ 10^{-5} Pa) for the SuperKEK electron linac.

In this experiment, Ir_5Ce and LaB_6 photocathodes were continuously irradiated by the sab-mJ class UV laser pulses for 50 hours under a 5×10^{-5} Pa, and measured the dependence of the QE on irradiation time.

Figure 5 shows the dependence of the QE of Ir_5Ce and LaB_6 photocathode on irradiation time of the fourth harmonic of an Nd:YAG laser. In case of using a LaB_6 photocathode, its QE gradually decreased with the laser irradiation. After irradiation for 50 hours, the QE dropped to 1/e of its initial value. The QE of Ir_5Ce photocathode, however, hardly decreased under the same conditions with

LaB_6. These results show that the Ir_5Ce photocathode is able to maintain its increased QE for a long term unlike multi-alkali photocathodes and Mg and so on even though it is under a reasonably low vacuum condition.

According to some prior researches, the 1/e lifetime of photocathodes depend on a degree of vacuum around them, and LaB_6 photocathode has a 1/e lifetime over 1000 hours under a 1.0×10^{-7} Pa [8]. Therefore, Ir_5Ce photocathode may have a 1/e lifetime over 1000 hours under high vacuum conditions considering our measurement.

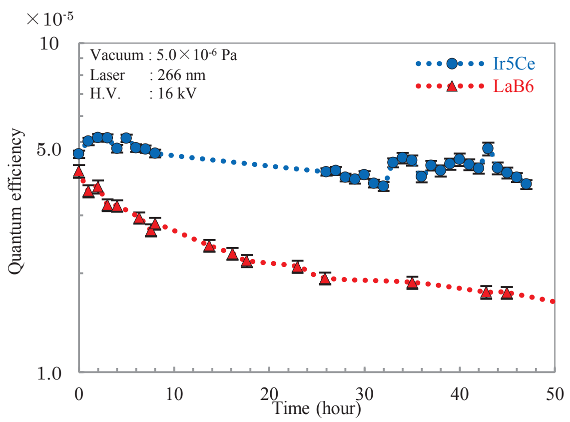

Figure 5: The dependence of QE on the irradiation time.

RF GUN STUDY AT THE TEST BENCH OF A KEK ELECTRON LINAC

We report the result of beam study at a 3-2 sector test bench of new-type RF gun in a KEK electron linac from April 2012. Figure 6 shows the existing beam line and the test bench at the 3-2 sector. This injector beam line at 3-2 sector is located at middle of the existing beam line and tilted at 26.56 degree (arctan1/2) to the main beam line. The injection beam line has the DAW-type RF gun, solenoid, chicane, traveling wave accelerating structure, doublet and bend magnet. An Ir_5Ce photocathode was installed in this RF gun and tested in this facility to generate the high charge and low emittance beams. The required electron beam parameters are 5 nC and 10 mm·mrad from the electron gun of the SuperKEKB linac.

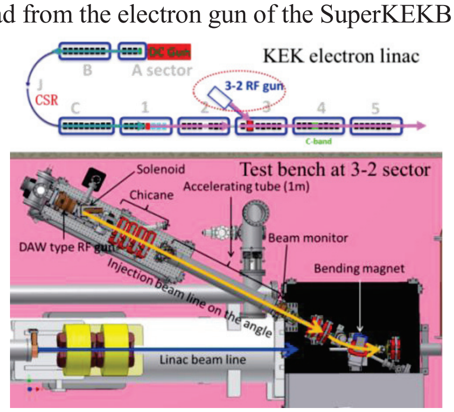

Figure 6: Figures of the existing beam line and the test bench at the 3-2 sector in KEK.

The result of a beam study at July 2012 is shown in Figure 7. According to this figure, we achieved to generate the electron beams with a maximum charge of 4.4 nC/bunch and accelerate them to the linac end.

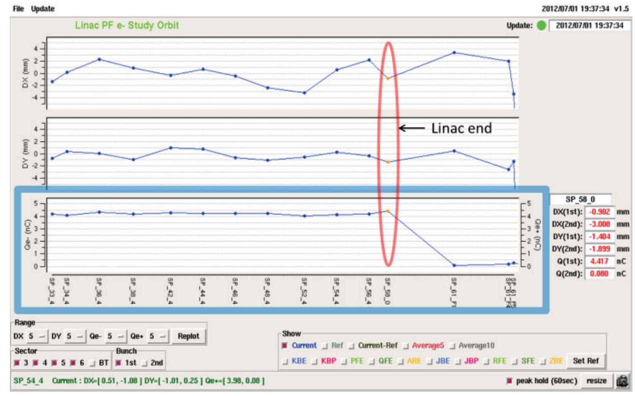

Figure 7: The result of a beam study at July 2012.

SUMMARY

We succeeded in developing an Ir_5Ce photocathode which satisfies the required parameters for SuperKEKB electron linac. Ir_5Ce photocathode has a reasonably high QE ($\sim9.1\times10^{-4}$ @213nm at room temperature) and long lifetime. Moreover, the QE of Ir_5Ce photocathode have been enhanced by heating, and it was increased to a maximum value of 2.70×10^{-3} by irradiating laser pulses of 213 nm and heating at 1006 °C. These great advantages of Ir_5Ce photocathode led to generate the electron beams with a maximum charge of 4.4 nC/bunch used by Ir_5Ce photocathode and DAW-type RF gun.

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