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ScienceDirect

Energy Procedia 131 (2017) 326–333

Energy Procedia

www.elsevier.com/locate/procedia

5th International Symposium on Innovative Nuclear Energy Systems, INES-5, 31 October – 2 November, 2016, Ookayama Campus, Tokyo Institute of Technology, JAPAN

Research and development of iridium cerium photocathode for SuperKEKB injector linac

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Abstract

We present the results of our investigation on iridium cerium compound as a photocathode material for the SuperKEKB photoinjector. A large-size iridium cerium compound with excellent machinability was obtained by a two-stage production method combining cold crucible induction melting and spark plasma sintering, and its usability as photocathode material was verified. The quantum efficiency (QE) of the non-activated sample was measured with 266 nm laser pulses to be 2.12×10^{-6}. The QE of the cleaned sample was found to be 1.49×10^{-4}, exhibiting an improvement by a factor ~ 70. The high resistance to poisoning against oxidization and carbonization of iridium cerium compound leads to useful properties, such as the compound being easily activate by laser cleaning and its reasonably high QE being maintained under non-ultra-high vacuum conditions. These significant advantages of the iridium cerium photocathode allow for the generation of high-charge electron beams with a bunch charge of 4.8 nC, when used with an advanced radio-frequency (rf) gun in the SuperKEKB injector linac. The QE of iridium cerium compound which was mounted in the rf gun was found to stay within the range of $(8 \sim 10) \times 10^{-5}$ for a year and a half without cathode maintenance such as laser cleaning.

Peer-review under responsibility of the organizing committee of the 5th International Symposium on Innovative Nuclear Energy Systems.

Keywords: Photocathode, Iridium cerium alloy, SuperKEKB, RF gun

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Peer-review under responsibility of the organizing committee of the 5th International Symposium on Innovative Nuclear Energy Systems.
10.1016/j.egypro.2017.09.430

1. Introduction

High precision measurements in the quark flavor sector are essential in search for new physics beyond the Standard model. To realize these measurements, SuperKEKB accelerator which is an asymmetric-energy and double-ring electron-positron collider and Belle II detector are designed and being constructed at High Energy Accelerator Research Organization (KEK) in Japan. This project requires an electron and positron collider with a peak luminosity of 8×10^{35} cm^{-2} s^{-1}, which would be 40 times higher than the highest luminosity achieved at KEKB. In order to achieve this target luminosity, the vertical beta function at the interaction point needs to be squeezed down to 1/20 and the beam current needs to be increased to twice that of KEKB while keeping the same beam–beam parameter in the vertical direction as KEKB [1]. However, the dynamic aperture is reduced due to the very small beta function at the interaction point. Thus the injector linac is required to provide the SuperKEKB rings with lower emittance and higher charge beams, as compared to the case with KEKB [1, 2]. Table 1 summarizes the required electron and positron beam parameters of the SuperKEKB linac. To achieve these beam parameters, the positron bunch intensity is boosted from 1 nC to 4 nC by introducing a flux concentrator as a beam focusing solenoid with a larger energy acceptance and then the emittance is shrunk in the horizontal and vertical planes by introducing a damping ring [3]. With regards to the electron, a new photocathode radio-frequency (rf) gun systems have been developed and the beam commissioning is in progress.

Photocathode rf guns are much effective in generating intense bright electron beams for a wide range of applications [4, 5, 6]. Electrons are generated via the photoelectric effect by irradiation of a suitable laser light on a photocathode which is mounted inside an rf gun. The rf fields in the gun cavities are synchronized with laser pulses and electrons are accelerated immediately after generation. The great advantage of using rf fields to accelerate electrons off of a gun cathode is that surface electric fields in excess of a few hundred of MV/m could be used, more than an order of magnitude greater than possible with DC fields. Therefore, the rf gun can generate high charge electron beams with energies of several MeV by accelerating within several tens of centimeters, giving reduced net space-charge effects during beam transport. In case of the SuperKEKB photoinjector, however, specified bunch charge (5nC) is so high that a standard on-axis coupled 1.5 cell rf gun is inadequate for achieving the required small beam size and emittance [7]. In order to overcome these problems, we have developed an advanced photocathode rf gun which is called the quasi traveling wave side-couple rf gun [7]. It has two side coupled cavities which are arranged staggered, and rf power with $\pi/2$ phase difference is fed into each cavities. As a result, this rf gun has a strong focusing field and a short drift space which keep the small beam size against the space charge effect. According to beam simulations of this rf gun, 5 nC electron beam can be accelerated to 11.5 MeV with 20 MW RF input while keeping the transverse emittance below 5.5 mm-mrad to exit of rf gun [7].

Table 1. Required electron and positron beam parameters for KEKB and SuperKEKB.

Beam parameters	KEKB		SuperKEKB	
	positron	electron	positron	electron
Beam energy	3.5 GeV	8 GeV	4 GeV	7 GeV
Bunch charge	1 nC	1 nC	4 nC	5 nC
Normalized vertical emittance (1σ)	2100 mm-mrad	300 mm-mrad	6 mm-mrad	20 mm-mrad

Proper photocathode material selection is the key to obtaining high-charge electron beams using a photocathode rf gun with long-term stability since the quantum efficiency (QE) and the intrinsic emittance of the electron source are determined by the properties of the photocathode material. Generally, semiconductor photocathodes (e.g., Cs_2Te or K_2CsSb) have been often used for a high average current and low transverse emittance photoinjector in many facilities [8, 9, 10] since they have extremely high quantum efficiency (QE ≈ 0.1 [8, 9]). These photocathodes, however, are not suitable for the SuperKEKB electron linac system, since the lifetimes of these photocathodes are not long enough for continuous operation without interruption for ~1 year. Another issue is that, due to the sensitivity of active layers on the cathode surface, these photocathodes must be operated in ultra-high vacuum environments (at least 10^{-8} Pa order [8, 9]) and there is a risk of cavity pollution caused by active materials. On the other hand, metallic photocathodes (e.g., Mg, Cu and LaB_6: lanthanum hexaboride) have sufficiently long lifetimes to operate an rf injector for a year. The QE of metallic photocathode is moderate (~ 10^{-4} [11, 12]), although