EXPERIMENTAL STUDY OF POSITRON PRODUCTION FROM MONOCRYSTALLINE TARGETS AT THE KEKB INJECTOR LINAC

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Abstract

We report a series of positron-production experiments from an axially-oriented single-crystal target by 4- and 8-GeV channeling electrons at the KEKB injector linac. The targets tested are tungsten crystals with different thicknesses (14.2 mm at maximum), and diamond crystals with two different thicknesses (7.25 mm at maximum). The axis <111> for the tungsten crystals and that <110> for the diamond crystals have been aligned to the electron beam by a precise goniometer. The positron-production efficiencies in the momentum range of less than 30 MeV/*c* were systematically investigated for each target by measuring the positron yield generated in the forward direction with a magnetic analyzer. The results show that the maximum positron-production efficiencies from the 9-mm-thick tungsten crystal and from the 7.25-mm-thick diamond combined with amorphous tungsten are 17% and 12%, respectively, larger than that from amorphous tungsten at the momentum of 20 MeV/*c*. In a series of the experiments using the crystal targets, the target thickness giving the maximum positron yield is clearly reduced in comparison with that of the amorphous tungsten alone due to the crystal effect.

INTRODUCTION

For future e^+e^- linear colliders and high luminosity B-factories, it is critically important to develop a high-intensity positron source. In a conventional method using an amorphous heavy metal target, the target thickness is determined to produce the largest number of low-momentum positrons, which can be accepted in the succeeding accelerator section. The momentum acceptance is typically 5–25 MeV/*c* and the optimum thickness is 4–5 X_0 for a 4–8 GeV electron beam. In this case, the only possibility to increase the positron intensity is to increase the incident electron intensity. However, the electron intensity is limited because of a heat load on the target. One promising method utilizing a crystal target was proposed by Chehab *et al.* [1] in 1989. The benefit of this method is on its high positron-production efficiency due to channeling radiation (CR) and coherent bremsstrahlung (CB), since CR and CB increase the number of low-energy photons in the radiation process. This results for the same positron yield in a thinner target compared with the conventional method. It is expected that the thin target relaxes the heat load problem, and that the spatial spread of positrons due to multiple scattering in the target is affected. There are two schemes on the target configuration for positron production utilizing a crystal target. One scheme is to use a heavy crystal target, such as a tungsten crystal, and the other is to use a light crystal target combined with amorphous tungsten. For the heavy crystal target, creation of channeling photons and positron production through e^+e^- pair production process proceed simultaneously in the heavy crystal target. On the other hand, for the latter target configuration, generation of photons by channeling proceeds in the light crystal target and the positron production proceeds in amorphous tungsten mounted just behind the crystal target. It should be experimentally investigated which target configuration shows larger amount of positron production since there have so far been only a few experimental results for the positron production on the basis of the crystal target. In this report, we summarize a series of the experiments of positron production by 4- and 8-GeV electron beams hitting tungsten crystal and diamond target, respectively [2-4].

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EXPERIMENTAL SETUP

Beam Line

Our experiment was performed in the beam switchyard of the KEKB injector linac. An electron beam with a pulse width of less than 10 ps (S-band single bunch) and with energies of 4 and 8 GeV impinging on a positron-production target at a repetition rate of 25 Hz. The beam charge (~0.1 nC/bunch) was measured by a wall-current monitor for each pulse. The transverse profile of the electron beam at the target was monitored by a screen monitor during the experiment. The angular spreads of the electron beam were estimated by the measured emittances and the beam sizes. However, since the electron beam impinged on the target after passing through a vacuum window made of 30-μm-thick stainless steel (SUS304), the angular divergences (*H*/*V*) of the electron beam at the target were estimated to be 55/55 μrad and 56/61 μrad in total by taking into account the multiple scattering at 4 and 8 GeV, respectively. These angular divergences were less than the critical angles required for the channeling condition, 0.61 mrad for tungsten crystal by 4-GeV electrons, and 0.13 mrad for diamond crystal by 8-GeV electrons. The main parameters of the incident electron beam are summarized in Table 1.

Table 1: Main beam parameters of the incident electron beam

	unit	4-GeVe^-	8-GeVe^-
Charge	nC	0.1	0.1
Emittances (x/y) $^{\$}$	nm	4.8/3.8	8.4/23
Angular div. (x/y) *	μrad	5.2/3.9	9.7/26
Angular div. (x/y)**	μrad	55/55	56/61
Beam Sizes (x/y) *	mm	1.85/1.95	1.75/1.70
Bunch length*	ps	7.7	7.7

*: FWHM, **: FWHM on the target, $: one standard deviation.

Monocrystalline Targets

Tungsten crystal targets (W_c) and diamond crystals were tested either alone or in combination with an amorphous tungsten plate (W_a). The surface mosaic spreads of these crystals on both sides were measured by an *X*-ray scattering method to be less than 0.5 mrad and 62 μrad for W_c's and diamonds, respectively. W_a's with different thicknesses from 3 to 18 mm with 3-mm steps were also installed on a horizontal movable stage to the beam axis in order to be used for combined targets and to make them possible to calibrate the positron yield. The tested targets are shown in Table 2.

Table 2: Thicknesses and radiation lengths of the tested targets

	Thickness [mm]	Radiation length [X_0]
Diamond	4.57	0.0372
Diamond	7.25	0.0589
W_c	2.2	0.628
W_c	5.3	1.51
W_c	8.9	2.54
W_c	12.0	3.43
W_c	14.2	4.06

Positron Spectrometer

The positrons emitted from the target in the forward direction were momentum-analyzed in a momentum range lower than 30 MeV/*c* by the magnetic field, where the bending angle was 60° from the beam axis.

Table 3: Acceptance of the positron spectrometer

P_{e-} (MeV/c)	Acceptance ($\Delta P \Delta\Omega$ [10^{-4} x (MeV/c)sr])
5	1.08 ± 0.03
10	2.47 ± 0.07
15	3.80 ± 0.10
20	4.81 ± 0.12
30	8.87 ± 0.21

The positron trajectory was determined by five collimators installed before and behind the magnetic field. The geometrical and momentum acceptance is summarized in Table 3, which was calculated by using the simulation code GEANT3. Other details are previously reported in [4].

EXPERIMNETAL RESULTS

Rocking Curves

Here, only the experimental results are described since the measurement and data analysis were carried out by using the similar procedure as the previous experiment [4]. A relative positron yield was measured as a function of the goniometer rotational angle around the *H* axis (rocking curve), while the angle around the *V* axis was fixed at the angular position giving the maximum yield. The result on the rocking-curve measurements for the 9-mm-thick tungsten crystal and the 7.25-mm-thick diamond crystal at the momentum of 20 MeV/*c* are shown in Figs. 1 (a) and (b), respectively. The rocking-curve peak width is defined by a full width at half maximum. The peak widths were obtained to be 40 mrad and 1.6 mrad for the tungsten crystal and the diamond target, respectively. Their widths are clearly larger than each critical angle for axial channeling. Figure 2 shows the variations of the peak width as a function of the tungsten-crystal thickness. The peak width increases slowly with the increase of the crystal thickness. It is of great benefit to apply such a tungsten crystal to a high-intensity positron source because the large peak width relaxes the accuracy of the crystal-axis alignment to the beam direction in the installation.

Enhancement of the Positron Yield

An enhancement of the relative positron yield was obtained from the rocking curve. The enhancement is defined by the ratio of the peak yield (on-axis) to the yield at the base region (off-axis) 30 (or 50) mrad apart from the crystal axis in the *H* scan. Figures 3 (a) and (b) show the results of the measured enhancement for the tungsten crystals and diamonds combined with an amorphous tungsten plate as a function of the crystal thickness at the momentum of 20 MeV/*c*. The enhancement of the tungsten crystal changes approximately from 1 to 3.4 depending on the crystal thickness, while for the 7.25-mm-thick diamond alone it is about 29. The results indicate that although for the thinner thickness the enhancements of the crystal targets are higher than that of amorphous tungsten targets based on the Bethe–Heitler process, it is clearly lower than that of the crystal targets, and for the thicker targets it approaches rapidly to one. It is presumed that for the thicker crystal targets the positrons generated in the crystal (or amorphous) tungsten are largely scattered because the channeling photons generated from the crystalline targets are relatively soft due to the lower depth of the crystal potential well. No clear dependence of the positron-yield enhancement with the positron momentum was observed in the measured region for both the crystal targets.

Figures 4 (a) and (b) show the variations of the positron-production efficiency depending on the target thickness, where the positron-production efficiency is defined as the ratio of the number of detected positrons to the number of incident electrons. The results also show that the positron-production efficiencies from the 9-mm-thick tungsten crystal and 7.25-mm-thick diamond target combined with a 9-mm-thick amorphous tungsten plate are 17% and 12%, respectively, larger than that from amorphous tungsten at each maximum positron yield with the momentum of 20 MeV/*c*. The shower-maximum thickness of each crystal is clearly reduced compared with that of the amorphous tungsten, which means that the radiation length is effectively reduced by crystal effect although the increase of the maximum positron-production yield is slightly larger than that from amorphous tungsten.

SUMMARY

A series of the positron-production experiments by 4- and 8-GeV channeling electrons hitting an axially-oriented tungsten crystals and diamonds have been successfully performed at the KEKB injector linac. The positron-production efficiencies from the crystal targets were measured as a function of the target thickness and as a function of the positron momentum in the momentum range of less than 30 MeV/*c*. The results show that when the crystal axis was aligned along the incident beam direction, a large positron-yield enhancement was observed for thinner crystal targets. The enhancement factor decreases as the target thickness increases. The positron-production efficiencies are 17% and 12% for the 9-mm-thick tungsten crystal and the 7.25-mm-thick diamond target combined with a 9-mm-thick amorphous tungsten plate, respectively, at the momentum of 20 MeV/*c*.

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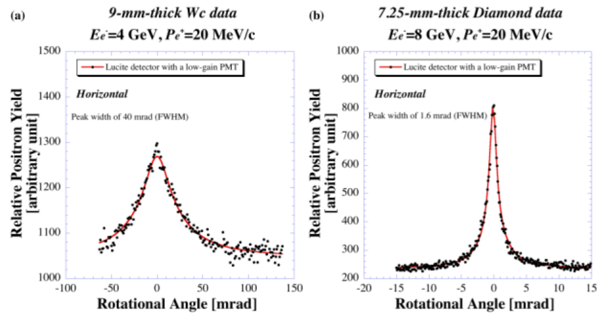

Figure 1: Rocking curves measured at the momentum of 20 MeV/*c* (a) for the 9-mm-thick W_c (E_{e-}=4GeV) and the 7.25-mm-thick diamond alone (E_{e-}=8GeV) as a function of the goniometer rotational angle around the *H* axis. The solid curves through the data are guides to the eye.

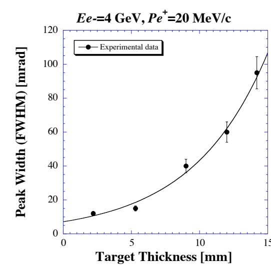

Figure 2: Variations of the rocking-curve peak width as a function of the thickness of the tungsten crystal measured at the momentum of 20 MeV/*c*.

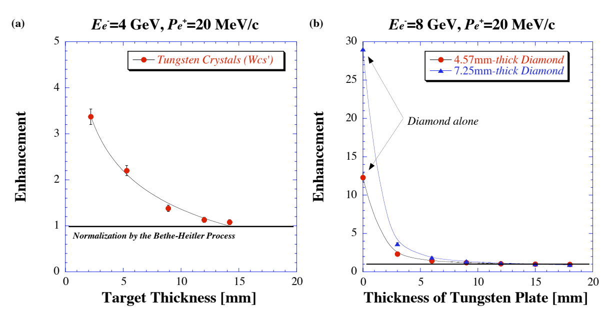

Figure 3: Variations of the positron-yield enhancement depending on the target thickness in total, (a) tungsten crystal and (b) diamond target. The solid curves drawn through the data are only to guide the eye.

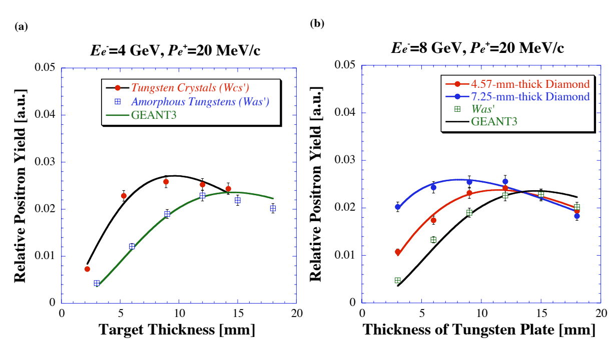

Figure 4: Variations of the positron-production efficiency depending on the target thickness in total, (a) tungsten crystal and (b) diamond target measured at the momentum of 20 MeV/*c*.