Positron Production from a Tungsten Single Crystal at the KEK 8-GeV Electron Linac

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In order to study a possibility of using a tungsten (W) single crystal as a high-intensity positron sourse at linear accelerators, we carried out an experiment to measure the positron production efficiency by the 8-GeV beam from the KEK electron linac. The single-bunch electron beam with a bunch width of 10 ps, 2 Hz repetition, and 0.2 nC/bunch intensity was injected along the <111> axis of the W single crystal mounted on a precision goniometer. Positrons were measured with a magnetic spectrometer placed downstream from the target at 0 degree with respect to the beam line. When the <111> axis of the crystal was aligned to the electron beam, about 5.1 times enhancement in the 2.2mm-thick crystal was observed compared to the positron yield for the disoriented crystal at $Pe^+ = 20$ MeV/c and about 1.7 times in the 9mm-thick one.

I. INTRODUCTION

For B-factories and future electron-positron linear colliders, a high-intensity positron source is very important in executing a high-luminosity beam collision. In a general way, positrons for accelerators are produced by the electromagnetic cascade shower when high-energy electrons hit a heavy-metal amorphous target such as tungsten (W). For the subsequent acceleration, the momentum and angle are restricted to the small range. For example, in the KEKB positron-station, the acceptance for produced positrons is $P_t \leq 2.4$ MeV/c, and 8.2 MeV/c $\leq P \leq$11.6 MeV/c. The thickness of W amorphous target is 14mm (4Xo), which is the optimum thickness for the 4-GeV incident electron beam. In this case, the number of captured positrons is at most about 0.1 positrons/electron. In such a conventional source, the positron intensity is limited by incident beam power capability and a heat load on the target. Then, one of the promising methods is to use a single crystal as a target for positron generation to increase the positron production efficiency.

The physical background of this method has two radiation processes reflecting the character of a crystal. One is the coherent bremsstrahlung. Another is the channeling radiation. When the high-energy electrons are injected into a crystal almost in parallel with its axis, electrons are captured by the axial potential of a crystal, move spirally (axial channeling), and then emit channeling radiation. When the photons from these radiation processes cause pair creation, the high-intensity positrons are obtained. These radiations have the advantage for production of positrons with comparatively low momentum, which match to the acceptance of the later acceleration. [1]

The possibility of a target for positron generation using the channeling radiation from a single crystal was proposed by Chehab et al. in 1989, and the simulation was performed. [2] Using the 1.2 mm-thick W single crystal, our group made a 'proof of principle' experiment by the 1.2-GeV electron synchrotron at the KEK Tanashi branch in 1996. When the crystal axis was aligned to the electron beam, 2.6 times enhancement was observed compared to the positron yield for the disoriented crystal at $Pe^+ = 20$ MeV/c. [3] Then, at the KEK 3-GeV Linac, an experiment was done with the target which combined a 1.7mm W single crystal and 7mm W amorphous, and 1.4 times enhancement was observed in 1998. [4] In 2000, using a 8-GeV short bunch electron beam from the KEK Linac, we carried out the experiment and observed about 5 times enhancement in the 2.2 mm W crystal, and 1.2-1.9 times enhancement in combination of 2.2 mm crystal and 5, 10 mm amorphous. [5] In the same year, Chehab et al. have begun the experiment with a electron beam of 5-40 GeV in CERN-SPS. [6] In April 2001, we measured the positron generation efficiency using W single crystals, whose thickness is 2.2 mm and 9 mm, at the KEK 8-GeV Linac. These systematic experiments are important for investigating the possibility of using a single crystal as a positron source in accelerators.

II. Experimental Method and Apparatus

The experiment was carried out with the test beam line of the beam switchyard at the KEKB injector Linac. The rear view of the setup is shown in Fig. 1. Parameters of the incident electron beam were;

Energy = 8 GeV
Intensity = 0.2 nC/bunch
Bunch width = 10 ps
Repetition rate = 2 Hz.

The incident electron beam was taken out in the atmosphere through a 100 μm SUS window, and injected to the target mounted on a goniometer. As shown in the right side of Fig. 2, the goniometer can move four axes of X, V, H, and A by stepping motors, and can change the angle of the target precisely with respect to the beam direction. The beam size at the target was about 1mm. The beam divergence was 15 μrad in the transverce direction and 72 μrad in the horizontal direction. We used the W crystal targets of 2.2 mm (mosicity ~1.5mrad) and 9 mm (mosicity ~0.5mrad). Amorphous W targets with different thickness from 3 to 18 mm by 3mm steps were also used for comparison. In the case of crystal targets, the electron beam was injected along the direction of the <111> axis. In the case of the amorphous, the target was mounted on X-Stage installed behind the goniometer, which can move in the X direction (perpendicular to the beam axis), and the data was taken by changing the thickness by moving the target in the X direction.

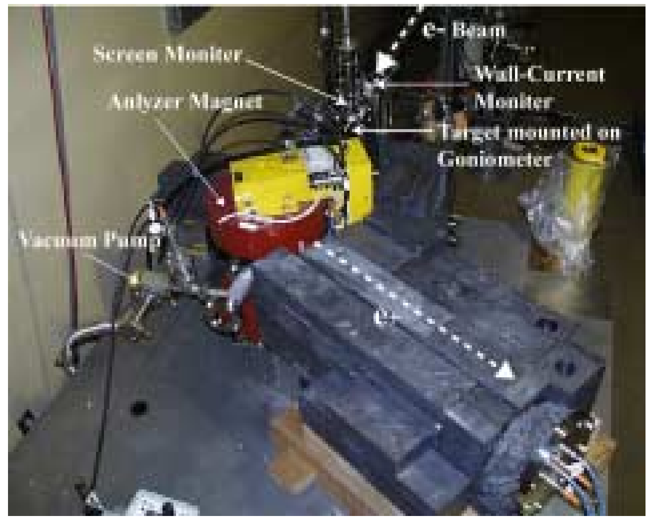

Fig.1. Photograph of the experimental setup.

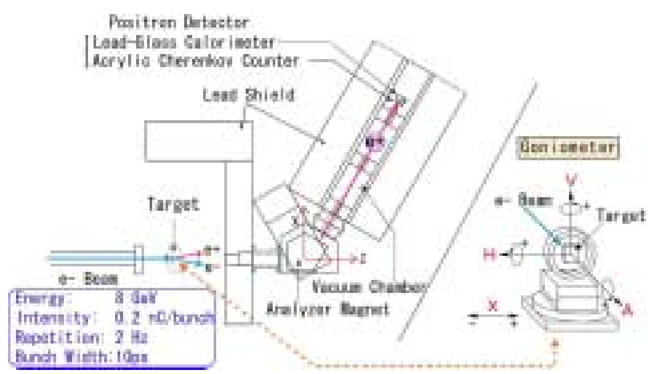

Fig. 2. Outline figure of the experiment

As shown in the left side of Fig. 2, the positrons generated from the target passed collimators of 30 mmφ and 40 mmφ installed in the vacuum chamber, and were bent 60 degrees from a beam axis with an analyzer magnet. An analyzer magnet current was set to select positrons in the momentum range between 10 and 20 MeV/c. Momentum selected positrons passed three collimators of 20 mmφ were detected by the positron detectors, an acrylic Cherenkov counter and a lead-glass calorimeter. Pulse heights of these counters were recorded bunch by bunch togeter with the beams intensity values, since the bunch width from the linac was 10 ps, within which positrons could not be resolved by detectors. Beam currents were measured by a wall-current monitor and recorded at the same time. Pedestals and backgrounds were measured frequently during the cource of experiments and subtracted from the signal data.

III. EXPERIMENTAL RESULTS

The positron yields at Pe^{+} = 20MeV/c as a function of the goniometer angle were shown for W single crystals of 2.2 mm and 9 mm thick in Fig.3. (Rocking curve) When the relative positron yields at Pe^{+} = 20MeV/c were compared at On-axis and Off-axis goniometer angles, 5.1 ± 0.1 and 1.7 ± 0.1 times enhancements for 2.2 mm and 9 mm-thick crystals were observed respectively. Angular widths of peaks were obtained by fitting to a Lorentzian function to be 9.0 mrad and 39.2 mrad FWHM for 2.2mm and 9mm thick crystals respectively.

The enhancements as a function of the positron momentum are shown in Fig.4. The figure indicates that the enhancement has a tendency to increase as the momentum becomes lower.

We also tested the amorphous target in the same way. For reference, Fig.5 illustrates a comparison of the positron yield of W crystal target with amorphous one. The vertical axis is the relative positron yield corrected by the acceptance for different amorphous targets. Assuming that the yields at Off-axis for the crystal targets are the same as for the amorphous with corresponding thickness, positron yields for crystal were plotted in the figure by multiplying the enhancement factors to the amorphous yields.

IV. SUMMARY

We conducted a positron production experiment from a W single crystal as a target in 8-GeV energy region using the electron beam from the KEKB injector linac. When the <111> axis of the crystal was aligned to the electron beam, 5.1 and 1.7 times more positrons than the disoriented crystal were observed at Pe^{+} = 20 MeV/c for 2.2 mm and 9 mm thickness respectively. These rocking curves show that peak widths increase as a crystal becomes thick. These angluar widths are very large when compared with the channeling critical angle at the 8-GeV electron beam; 0.43mrad (the Lindhart angle), and the multiple scattering angles; 1.34 mrad (in 2.2mm) and 2.78 mrad (in 9mm). We are still

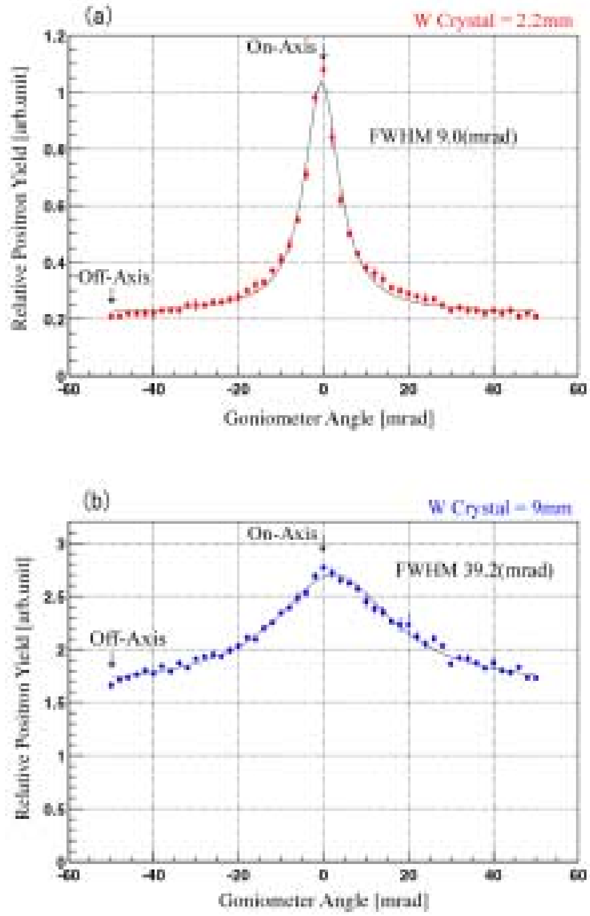

Fig.3. Rocking curves for W single crystal at Pe^{+}=20MeV/c, Ee^{-}=8GeV. (a) 2.2mm-thick W crystal target. (b) 9mm-thick W crystal target. The curves are fits to a Lorentzian function plus a constant yield.

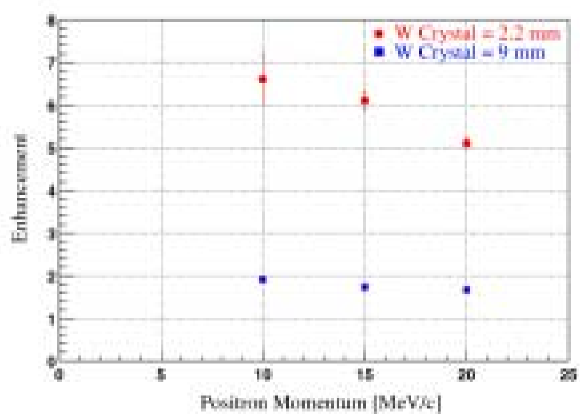

Fig.4. Momentum dependence of the positron enhancement.

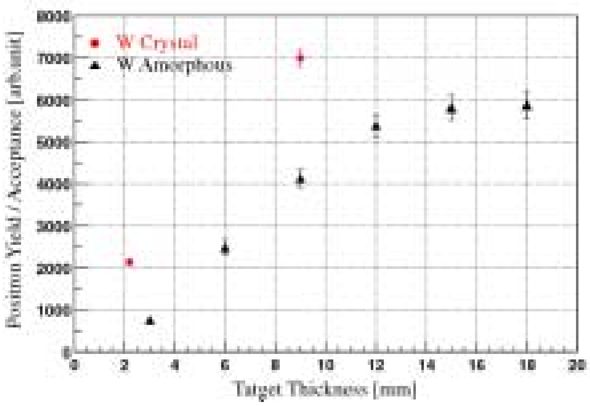

Fig.5 . Relative positron yield from W crystal and W amorphous. Errors are statistical only.

investigating the possible cause of the increase of angular width of the rocking curve.

About the momentum dependence of the enhancements, the enhancement increases as the momentum becomes lower. This is advantageous for the acceptance of the subsequent acceleration of positrons at the injector linac.

By comparing the positron yields from the crystal and amorphous targets, it is noted that the much thinner crystal target can be used than the amorphous target for a given amount of positrons. It is remarkable that the positron yield of the 9 mm-thick W crystal is comparable to that of 14 mm-thick W amorphous, which is used at the positron station of the KEKB linac. There are possibilities to reduce the multiple scattering and a heat load in the target by making a target thinner.

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