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Increase in the beam intensity of the linac-based slow positron beam and its application at the Slow Positron Facility, KEK

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Abstract. Recent developments of the Slow Positron Facility at the Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK) are reported. We have modified the converter/moderator assembly for slow positron beam production, yielding an increase of an order of magnitude in the intensity of the beam. The first observation of the photodetachment of the positronium negative ion (Ps$^-$), and the installation of a reflection high-energy positron diffraction (RHEPD) station and the initial data obtained are reported.

1 Introduction

Recent developments of the Slow Positron Facility (SPF) at the institute of materials structure science (IMSS), High Energy Accelerator Research Organization (KEK) are reported. The facility, equipped with a dedicated 55 MeV linac, provides a high-intensity, pulsed slow positron beam. It operates in a short-pulse mode (10 ns pulse-width) and a long-pulse mode (1 μs pulse-width) at frequencies of up to 50 Hz. Recently, the converter/moderator assembly for slow positron beam production has been modified, yielding an increase of an order of magnitude in the intensity of the slow positron beam. This article describes the modifications made and reports briefly two experiments, namely the photodetachment of the positronium negative ion (Ps$^-$) and reflection high-energy positron diffraction (RHEPD) by using the intensified slow positron beam.

2 Increase in the beam intensity by modification of the slow positron production unit

Figure 1 shows schematic diagrams of the old converter/moderator assembly (left) and the new one (right). With the old converter/moderator assembly, the 25 μm-thick W foils were arranged so that the surfaces of the foils were perpendicular to the direction of the accelerated electron (e$^-$) beam. The converter/moderator and the extraction grid were electrically isolated from each other with the former connected to a high voltage supply (up to 35 kV). A floating voltage of 9 V was applied between them using a dry cell. The slow positrons (e$^+$) were extracted in the direction perpendicular to the accelarated electrons. The W foils used as the moderator had been annealed by the passage of an electric current before assembling. The converter was made of Ta.

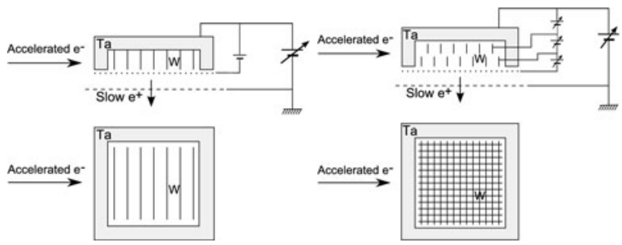

Fig. 1. Schematic diagrams of the old converter/moderator assembly (left) and the new one (right).

The main modifications of the converter/moderator assembly were as follows: (i) 25 μm-thick W foils of sizes 4.8 mm × 21 mm and 4.8 mm × 29 mm were set in a lattice; (ii) two sets of lattices were used; (iii) the Ta converter, W moderator lattices and extraction grid were electrically isolated from each other, and connected to a cascade voltage supply (up to 35 kV + up to 10 V × 3). The moderators were annealed after the W strips were set in lattices.

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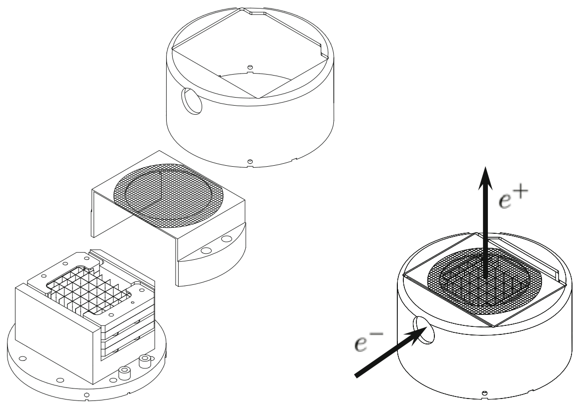

Fig. 2. The new converter/moderator unit by parts: the Wehnelt cylinder, the extraction grid and the converter/moderator. A schematic of the assembled unit is also shown.

Table 1. The cascade voltage applied to the new converter/moderator unit and the intensity of the slow positron beam obtained. In this table, HV is the voltage applied to the converter, and $F1$, $F2$, $F3$ are the cascade voltages applied to the first moderator, the second moderator and the extraction grid, respectively, and I is the relative intensity.

#	HV/kV	$F1$/V	$F2$/V	$F3$/V	I (arb. units)
1	10	–10	–10	–10	11.0
2	10	–10	–10	0	10.2
3	10	0	–10	–10	9.5
4	10	0	–10	0	9.2
5	10	–10	0	–10	9.0
6	10	–10	0	0	8.0
7	10	0	0	–10	7.0
8	10	0	0	0	7.0

When annealing, they were encased in covered boxes of 50 μm-thick W foil and the boxes were irradiated on the covering lids with an electron beam welder. The annealing temperature was elevated to around 2400 °C, considerably higher than is common practice for W positron moderators. The vacuum of the welder chamber was 1×10^{-5} torr.

The converter and the frame for the moderator were made of Ta. Figure 2 shows, schematically, the new unit by parts: the Wehnelt cylinder, the extraction grid and the converter/moderator. A schematic of the assembled unit is also shown. The slow positrons were extracted in the direction perpendicular to the linac electron beam, out of the lattice face.

A comparison of the intensity of the slow positron beam before and after the modification of the unit showed an increased of an order of magnitude to 7×10^7 slow e^+/s in the long pulse mode. Later, the intensity fell slightly but remained at around 5×10^7 slow e^+/s.

The variation of the intensity of the slow positron beam produced with the new unit as a function of the cascade voltages applied are also investigated and listed in Table 1. In this table, HV is the voltage applied to the converter, and $F1$, $F2$, $F3$ are the cascade voltages applied to the first moderator, the second moderator and the extraction grid, respectively, and I is the relative intensity. Condition #7 is similar to that of the old assembly using a 9 V dry cell as the floating voltage. The intensity of #1 is about 1.6 times as much as that of #7. It was observed that applying a voltage to the second moderator ($F2$) resulted in the highest intensities. These results indicate that the annealing procedure and geometry have given the gain about six times over the old system.

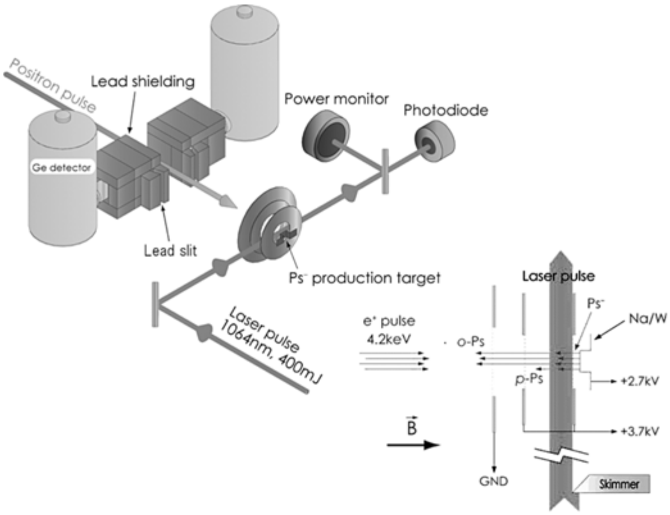

Fig. 3. Details of the setup for Ps^- photodetachment experiment.

3 Photodetachment of the positronium negative ion (Ps^-)

The positronium negative ion (Ps^-) is an exotic system composed of one positron and two electrons bound through Coulomb interaction. Nagashima et al. established a method to produce a stable Ps^- source efficiently [1,2]. When the pulsed slow positrons in a short pulse mode at the SPF were injected onto a Na-coated W surface, 1.4% of the positrons were emitted back as a Ps^- pulse. The ions were then successfully photo-detached into a neutral positronium atom and an electron by using an intense photon beam from a Q-switched Nd:YAG laser (1 J/pulse at 1064 nm, 12 ns FWHM, 25 pps) synchronized to the Ps^- bunch [3]. Figure 3 shows the details of the crossed beam region. The intensity of the Doppler shifted annihilation γ-rays from the accelerated Ps^- ions decreased upon photon irradiation. This indicates that the Ps^- ions are converted into neutral Ps, of which 3/4 is ortho-Ps and so does not annihilate into 2γ. The lower limit of the Ps^- photo-detachment cross section estimated from the decrease is 2.1×10^{-17} cm^2, which is consistent with theoretical predictions [4–6].

This achievement marks the first step toward the creation of an energy tunable Ps beam that can be used in ultra high vacuum environments.

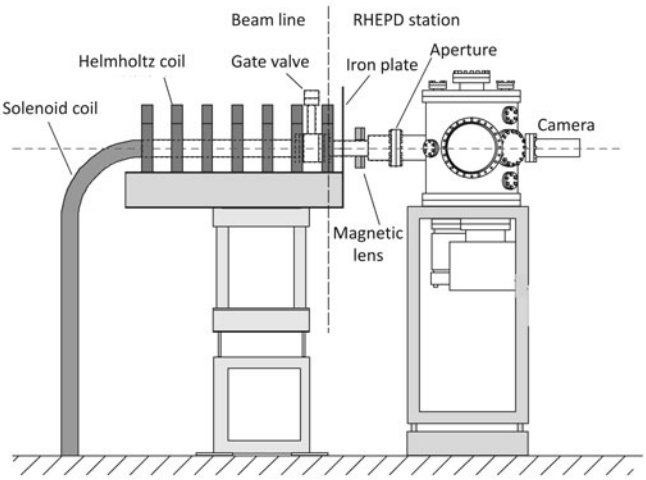

Fig. 4. Positrons transported magnetically are introduced into the magnetic-field-free region, which is magnetically separated by a 3 mm thick iron plate from the beam line. Then part of the positron beam goes through an aperture ($\phi 10$ mm), a collimator ($\phi 3$ mm $\times$ 30 mm) and an einzel lens, and reaches the sample in the RHEPD chamber.

4 Installation of a RHEPD station and the initial data obtained

A station to observe reflection high-energy positron diffraction (RHEPD) has been connected to a beamline branch. The RHEPD [7] is a positron version of reflection high-energy electron diffraction (RHEED).

A remarkable feature of RHEPD is that, since the crystal potential for the positron is positive, positrons incident on the surface with a small glancing angle are totally reflected. Therefore, positrons are more sensitive to the topmost layers of crystals than electrons. RHEPD was put to practical use by Kawasuso and Okada [8]. Fukaya et al. subsequently used a ^{22}Na based slow positron beam at Japan atomic energy agency (JAEA) to determine the structure of the In atom chains on the Si(111) surface below the phase transition temperature [9] and studied surface plasmon excitations [10].

Figure 4 shows the schematic view of the RHEPD station installed. Positrons transported magnetically are introduced into the magnetic-field-free region where separation is achieved by a 3 mm thick iron plate from the beam line. Then part of the positron beam goes through an aperture ($\phi 10$ mm), a collimator ($\phi 3$ mm $\times$ 30 mm) and an einzel lens, and reaches the sample in the RHEPD chamber. The beam spot at the sample is 2.1 mm. (The initial beam diameter just outside the converter/moderator unit is about 20 mm.)

The intensity of the diffracted beam in the new apparatus was found to be 14 times greater than that of former measurements with the ^{22}Na based beam at JAEA. Figure 5 shows an RHEPD pattern obtained from the Si(111)-7×7 surface. The fractional spots from the 7×7 superstructure are clearly seen. Figure 6 shows the RHEPD rocking curve of specular spots from the same surface.

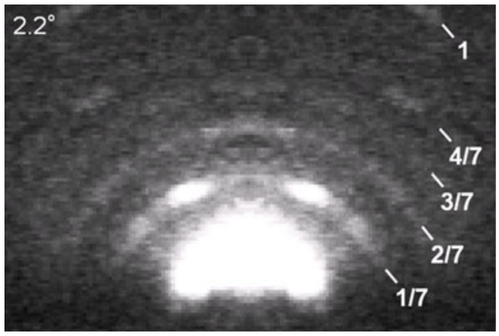

Fig. 5. Observed RHEPD pattern for the Si(111)-7×7 surface. The incident positron energy and the glancing angle are 10 keV and 2.2°, respectively.

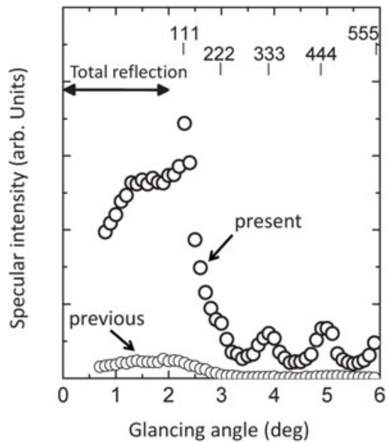

Fig. 6. Rocking curve data obtained for the Si(111)-7×7 surface. Previous data observed with a ^{22}Na-based slow positron beam and the present data are shown.

Previous data obtained with a ^{22}Na-based slow positron beam is also shown. In addition to the intense total reflection and the (111) Bragg reflection peaks, the (333), (444) and (555) Bragg reflection peaks are clearly observed.

We are preparing a brightness enhancer (remoderator) to be installed next year to obtain stronger and more detailed diffraction patterns.

5 Conclusion

Recent developments of the Slow Positron Facility at IMSS, KEK are reported. We have modified the converter/mod-erator assembly for slow positron beam production, yielding an increase of an order of magnitude in the intensity of the beam. Experiments on the photodetachment of Ps$^-$ have been performed with the new beam. An RHEPD station was installed and initial data obtained. The intensity of the diffracted beam was found to be 14 times greater than that of the former measurements with a ^{22}Na-based beam.

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