3rd China-Japan Joint Workshop on Positron Science (JWPS2017)
JJAP Conf. Proc. **7**, 011301 (2018) https://doi.org/10.7567/JJAPCP.7.011301

Progress Report on Construction of a Low-energy Positron Diffraction (LEPD) Experiment Station at KEK

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(Received October 2, 2017)

A low-energy positron diffraction (LEPD) experiment station was developed at the Slow Positron Facility, High Energy Accelerator Research Organization (KEK). An electron-accelerator-based slow-positron beam with an energy of 5 keV was magnetically transported and focused on a transmission-type Ni remoderator to achieve a 50 eV–500 eV brightness-enhanced beam in a non-magnetic space. A LEPD detector with center holed retarding meshes, Chevron-type microchannel plates, and a delay-line detector (DLD) was installed. A newly developed pulse stretching system was used to stretch the initial positron-pulse width of 1.2 μs to 200 μs–20 ms to avoid multiple hit events within the position analysis time of the DLD.

1. Introduction

Low-energy positron diffraction (LEPD) is the positron counterpart of low-energy electron diffraction (LEED) [1]. LEPD offers the possibility of easing difficulties in the structure determination of high-Z materials with LEED and that of surface holography [2].

The first LEPD experiment was reported by K. Canter's group at Brandeis University in 1980 [3]. They developed a LEPD system with a radioisotope-based slow-positron beam and demonstrated that LEPD showed better agreement between theoretical and experimental diffraction intensity profiles than LEED [4]. Later theoretical works revealed the benefits of LEPD: no forward focusing resulting in a lower chance of multiple scattering and a simple and smooth scattering factor resulting from no exchange interaction with material electrons as well as weak relativistic effects due to the repulsive force from the core [5, 6]. These advantages are of great significance for surface atomic-structure analysis especially on high-Z materials. LEPD also has an advantage of high surface sensitivity due to a short mean-free path compared to LEED. Despite these promising properties, however, no further LEPD experimental research followed the pioneering works at Brandeis University.

Recently, we have developed a LEPD experiment system with a linear electron accelerator (linac)-based slow-positron beam at the Slow Positron Facility (SPF), KEK [7–9], where a high-intensity, pulsed slow-positron beam is provided. Our objective is to make LEPD a practical tool of high-precision structure analysis of surfaces, especially those for emerging materials for spintron-

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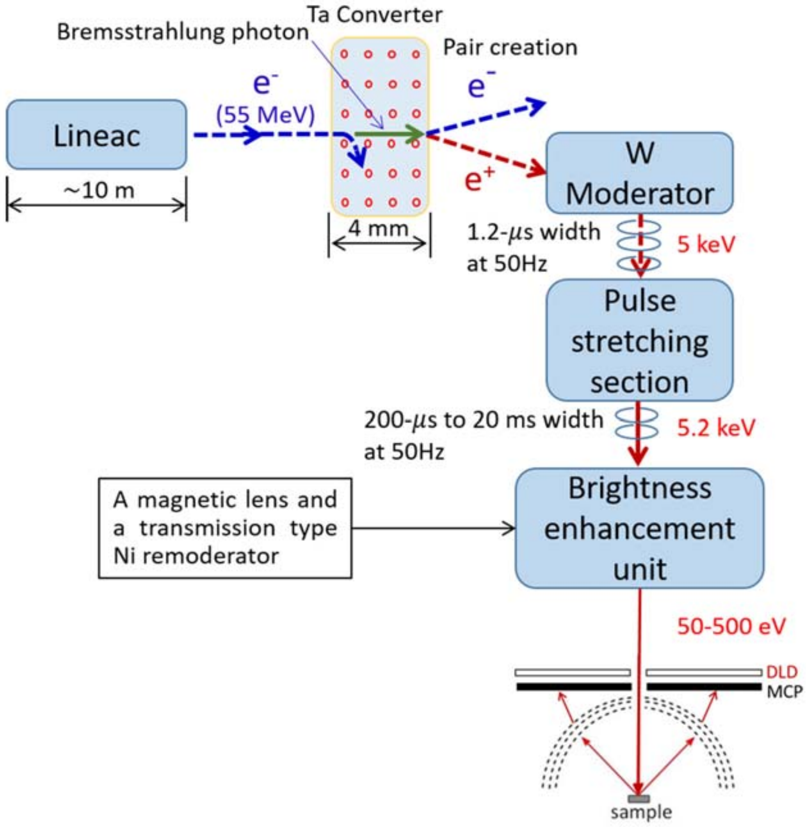

Fig. 1 An overview of the whole LEPD system at the KEK-SPF. A pulsed slow-positron beam is generated with a linear electron accelerator (linac), Ta converter, and W moderator. The magnetically guided pulsed slow-positron beam is stretched in a pulse stretching section and released into a magnetic field free space. Then the brightness-enhancement system with a magnetic lens and a transmission type remoderator (150-nm-thick Ni foil) is effectively used to achieve a brightness enhanced beam with an energy of 50 eV–500 eV, which is transferred to the sample through a LEPD detector with electrostatic lenses. Diffraction patterns are observed by a set of center-holed Chevron MCP and DLD.

ics including high-Z atoms, which are difficult to analyze by LEED. We also plan to realize surface holographic reconstruction by LEPD, which was predicted to be better suited than that by LEED [2].

2. LEPD system at the KEK-SPF

2.1 Overview of the whole system

Our LEPD system will be described in detail elsewhere [10]. Briefly an overview of the LEPD system is given here together with those of the pulse stretching and the brightness enhancement system.

A conceptual chart of the whole LEPD system is shown in Fig. 1. A dedicated linac injects a pulsed electron beam with an energy of ~50 MeV to a Ta converter and causes positron-electron pair creation. A part of the fast positrons are moderated at a W moderator [7]. For the LEPD experiment, a beam with an energy of 5 keV is guided magnetically through a grounded beam line, and released into a nonmagnetic space. Then a brightness-enhancement unit with a magnetic lens and a 150-nm-thick Ni foil [11] enhanced the brightness of the beam, which is then transported to the sample through the LEPD detector with an energy of 50 eV–500 eV with electrostatic lenses. For the LEPD detector, we installed three retarding meshes, a set of center-holed Chevron-type microchannel plates (MCP) and a delay line detector (DLD) for obtaining the diffraction pattern digitally, i.e. in a counting base; we cannot use a camera to observe a diffraction pattern because of geometrical conflict with the beam line. Since the DLD has a limited allowance for the time between two hits, the positron pulse width of 1.2 μs is stretched to 200 μs–20 ms with a newly developed pulse stretching system.

2.2 Pulse stretching system

The high-intensity pulsed slow-positron beam at KEK-SPF has been successfully used for experiments on positronium negative ions (Ps^-) and positronium time-of-flight (Ps-TOF) with 1 ns–12 ns (variable) pulse width (short-pulse mode), and total-reflection high-energy positron diffraction (TRHEPD) with 1.2 μs pulse width (long-pulse mode) [6–8]. The maximum intensity is obtained with the long-pulse mode, where $\sim 10^6$ slow-e^+ are contained in every pulse, or a density per unit time of $\sim 10^{12}$ slow-e^+ s^{-1} within the pulse. This density would cause problems due to multi-hits on the MCP-DLD system even for the diffracted beam.

The newly developed pulse stretching system for materials science experiments [12] consists of an entrance electrode, a 6-m-long trapping electrode, and an exit electrode, all cylindrical, and installed by aligning the central axis with the beam-line tube. The voltage of the entrance electrode, normally kept at 5.75 kV, is temporarily lowered to 4.8 kV to let a 1.2-μs-width positron pulse from the converter/moderator unit with an energy of 5.0 keV into the trapping electrode. Positrons then travel along a solenoid magnetic field down to the exit electrode kept at 5.2 kV and are reflected back. The entrance electrode voltage is raised back to 5.75 kV before the front of the positron bunch comes back so that the positrons are trapped. The trapping electrode voltage is then increased gradually, letting the positrons spill over the exit electrode. By adjusting the sweeping speed of the trapping electrode voltage, we obtain a stretched pulse with a width from 200 μs to 20 ms with a fixed energy of 5.2 keV. The minimum stretched width of ~200 μs is limited by the frequency response of the amplifier used for controlling the trapping-electrode voltage, and the maximum of 20 ms is the limit imposed by linac repetition frequency of 50 Hz.

For the present LEPD system, we have stretched the pulse width to be 200 μs, which is long enough to avoid the multiple-hit problem of the MCP-DLD system, and at the same time gives the minimum background caused by dark current in the detector by setting a time window to select relevant data only within the 200 μs pulse width.

2.3 Brightness enhancement system

Figure 2 shows a photo of the LEPD station (Fig. 2 above) together with a diagram of the brightness enhancement system, electrostatic lenses, and the LEPD detector (Fig. 2 bottom). A stretched, pulsed beam is transported magnetically, released into a nonmagnetic space, and focused on a 150-nm thick Ni foil (remoderator). This foil with a support ring is cleaned before use by atomic hydrogen bombardment [11] in a separate chamber isolated by a gate valve.

The remoderated beam is transported by two sets of Einzel lenses, which are covered by a Mu-metal cylinder. The thin nozzle goes through the center hole of the LEPD detector, which is composed of a MCP-DLD and retarding meshes, and shields the beam from the electrostatic field generated by the detector.

In order to check the LEPD beam, we placed a MCP at the sample position and observed that the full width at half maximum of the beam diameter was less than 1.5 mm from 50 eV to 300 eV. We also checked the incident angular spread by moving the beam monitoring MCP along with the beam trajectory to be within $\sim\pm 1^\circ$ for those energies. These values meet the required parameters necessary for LEPD [13].

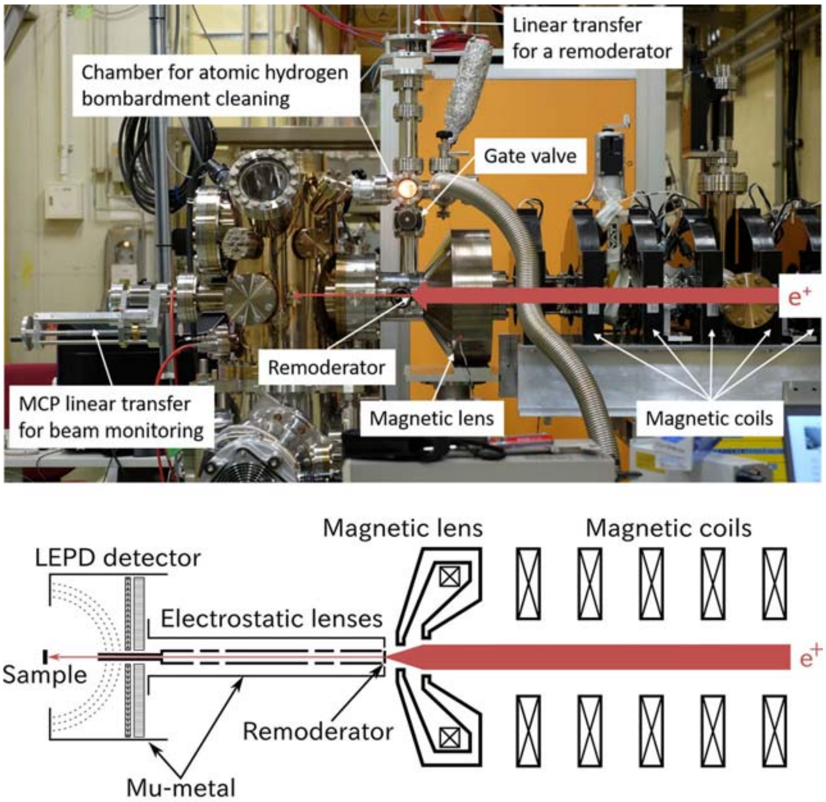

Fig. 2 Photo of the LEPD station (above) and a diagram of the brightness enhancement system, electrostatic lenses for transporting the remodrated beam, and the LEPD detector (bottom). These electrostatic lenses and the detector are covered by a permalloy cylinder. The thin nozzle on the left hand side of the figure goes through the center holes of the MCP and the DLD.

2.4 Detection system

The LEPD detection system is composed of three retarding meshes, a Chevron-type MCP, and a DLD with a central hole as shown in Fig. 3 left. To check the LEPD detector settings, we used a beam monitoring MCP as an electrostatic mirror to deflect back the beam to the LEPD detector (Fig.3 left). This MCP assembly, having a mesh kept at ground potential in front of the MCP, was slightly tilted against the incident beam direction. By applying an electrostatic potential of ($V_{RM} + 2$) V, where V_{RM} is that applied to the remoderator, to the MCP front to repel the beam, we observed the deflected beam at a position outside of the center hole of the MCP-DLD detector (Fig. 3 right). We applied ($V_{RM} - 10$) V to the second and third retarding meshes to block inelastically scattered positrons, and ($V_{RM} - 300$) V to the MCP front to keep the injection energy of elastically scattered positrons to the MCP front to be ~300 eV, and [($V_{RM} - 300$) + 2400] V to the MCP back, as indicated in Fig. 3 for $E = 140$ eV.

3. Summary

We have constructed a LEPD experiment station with a MCP-DLD detector at the KEK-SPF. Since the DLD has a limited allowance for multiple hit events, we have used a pulse stretching system, which stretches the 1.2 μs pulse width to 200 μs–20 ms to avoid the multi-hit problem. The stretched, pulsed beam is magnetically transported, released into a non-magnetic space, and focused

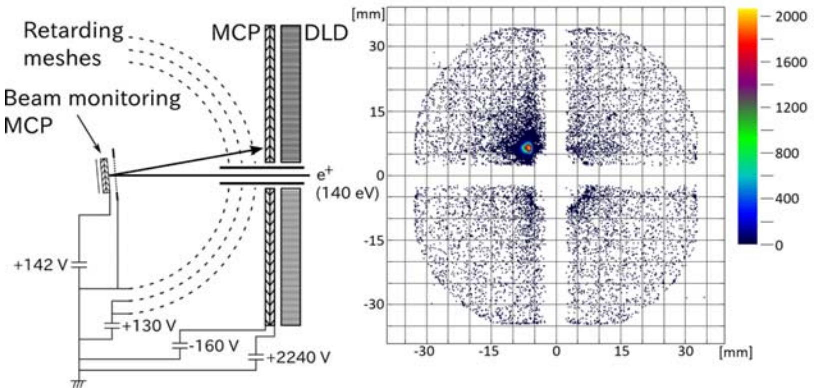

Fig. 3 (Left) A beam monitoring MCP assembly with a fluorescent screen and a grounded mesh in front of the MCP front. This assembly was slightly tilted against the incident beam trajectory and also used as an electrostatic mirror by applying an electrostatic potential to the MCP front at a slightly higher voltage than the beam energy. The potential values correspond to a beam energy of 140 eV. (Right) The deflected beam observed by the MCP-DLD.

on a transmission-type Ni remodetor by a magnetic lens. The remoderated beam was transported by electrostatic lenses in non-magnetic space to the sample position. The full width at half maximum of the beam diameter at the sample position was found to be less than 1.5 mm from 50 eV to 300 eV. We also observed the direct beam with the MCP-DLD detector by deflecting it at the sample position with an electrostatic mirror, and checked the detector settings.

We are planning to observe diffraction patterns with this system. Surface holography is one possible extension of this system.

Acknowledgment

This work was supported by MEXT/JSPS KAKENHI Grant Numbers JP24221007 and JP16K13692, Toray Science and Technology Grant, the Cross Ministerial Strategic Innovation Promotion Program (SIP, unit D66). Experiments were conducted under the approval of the PF PAC (proposal Nos. 2014G636, 2015S2-002, 2016S2-001, 2016S2-006) and under the auspices of the QST-KEK Joint Development Research.

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