4 Slow Positron Facility

4-1 Overview

The Slow Positron Facility of the Photon Factory, equipped with a dedicated 55 MeV, 600 W linac, provides a high intensity, pulsed slow positron beam [1, 2]. The electrons accelerated by the linac are bombarded on a Ta converter, where Bremsstrahlung produces electron-positron pairs. The positrons so produced are moderated using a W foil moderator. The pulse width is determined by the pulse structure of the linac: it is 1 μs (long pulse mode) or 1–10 ns (variable, short pulse mode) at frequencies of up to 50 Hz.

A variable high electrostatic tension (up to 35 kV) is applied to the slow positron production unit (Ta converter and W foil moderator); the obtained energy-tunable slow positron beam is magnetically guided to the experiment hall and then branched to experimental stations. The transportation of the beam with energy of up to 35 keV through a grounded beamline duct gives flexibility for experiments with grounded apparatus. This high energy transport capability is unique among high-intensity positron beam facilities in the world.

The beam intensities are 5×10^7 slow-e^+/s in the long-pulse mode, and 5×10^6 slow-e^+/s in the short-pulse mode.

In FY2012, the racks for the coil current supply, which were standing near the stations, were relocated to make more space for the near-future expansions of the beamlines. Consequently all the wirings from the current supply to the coils of the beamline were renewed. All the experimental stations were also relocated; the reflection high-energy positron diffraction (RHEPD) station connected to the beamline SPF-B1 was moved to SPF-A3, the station for the photodetachment of the positronium negative ion (Ps^-) connected to SPF-A3 was moved to SPF-B1, and the positronium time-of-flight (Ps-TOF) station connected to SPF-A1 was moved to SPF-B2. The purpose of this rearrangement was twofold: (1) to use the lab space more effectively and (2) to aggregate

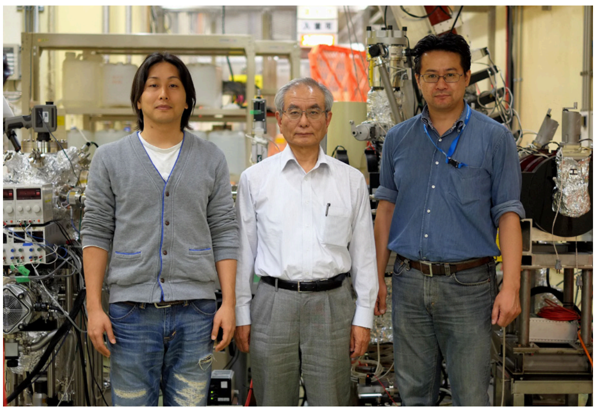

Figure 1: Members of Slow Positron Facility (SPF).

the stations that use short pulses in the Klystron Gallery Lab on the ground floor and those that use long pulses in the Test Hall on the basement floor. Specifically, in addition to the RHEPD apparatus transferred from the Japan Atomic Energy Research Agency (JAEA), Takasaki, a new apparatus was constructed.

The currently available stations and the connected beamline branches are summarized below:

SPF-A3: reflection high-energy positron diffraction (RHEPD)
SPF-B1: photodetachment of the positronium negative ion (Ps-)
SPF-B2: positronium time-of-flight (Ps-TOF)

4-2 Two Projects Running in Connection with the Activities

Grant-in-Aid for Scientific Research (S) "Development of High-Brightness and High-Intensity Positron Diffraction and its Application to Surface Studies" (Project Leader: Toshio Hyodo (KEK))

Reflection high-energy positron diffraction (RHEPD), the positron version of reflection high-energy electron diffraction (RHEED), is in operation for surface structure analysis. A station for low- energy positron diffraction (LEPD), the positron version of low-energy electron diffraction (LEED) is under development for the same purpose. Positron diffractions are easier to interpret than electron diffractions because: (1) the exchange interaction with material electrons is absent; (2) the surface sensitivity of the positron is higher owing to larger inelastic scattering cross section, (3) the scattering factor for the positron falls off as smoothly as that of X-rays because it is repelled by the nuclei, and (4) total reflection takes place owing to the positive crystal potential energy for the positron.

Since the positron is an antiparticle and so not found in everyday life, it is not easy to make a high-brightness and high-intensity beam for diffraction experiments in the laboratory. This project solves this problem by making use of the high-intensity slow-positron beam of the Slow Positron Facility and enhances its brightness.

The extremely high sensitivity of positron diffraction to the surface makes it possible to determine the details of surface atomic configurations which cannot easily be done by X-ray or electron diffractions or scanning tunneling microscope (STM). The direct determination of surface atomic geometry will be attempted in two ways: by analyzing the RHEPD patterns taken under total reflection conditions with the Patterson function, and by using the holographic reconstruction of the atomic arrangement using the LEPD spectra taken at various energies.

Progress in FY2012: The results of measurements on a Pt-deposited Ge surface conducted in FY2011 were published [3]. Construction of a second RHEPD station was started on beamline SPF-B1 in the Test Hall on the basement floor to make effective use of experiment space. A brightness enhancement unit using a transmission-type W film (100 nm) remoderator was installed, which enhances the brightness of the magnetically guided beam by about 50,000 times. Using this refined beam, the development of total reflection high-energy positron diffraction, investigation of the structure of the TiO2 surface, and that of silicene have started.

Grant-in-Aid for Scientific Research (S) "The Evolution of Positronium Beam Science using the Technique of Photodetachment of the Positronium Negative Ion" (Project Leader: Yasuyuki Nagashima (Tokyo University of Science)

This project is being conducted in a laboratory of the Tokyo University of Science and the Slow Positron Facility at KEK. Only a general introduction and the performance at KEK are described here.

The bound state of an electron and a positron, is called positronium (Ps). Ps is the lightest "atom" which is metastable against self-annihilation into γ-rays with a lifetime of 125 ps or 142 ns. An energy-tunable beam of Ps will be a powerful tool for investigating material surfaces. However, the production of a beam with sufficient intensity and appropriate energy range was difficult to realize; the only beam of Ps produced before this project started used charge exchange between positrons and gas molecules in the energy range below 400 eV [4].

This project aims to produce an energy-tunable Ps beam using photodetachment of positronium negative ion (Ps^-), a bound state of two electrons and a positron, in an ultra-high-vacuum environment. Recently Nagashima (project leader) et al. found that the Ps^- is emitted efficiently from alkali metal coated tungsten surfaces when bombarded with slow positrons [5]. Since the ion has a negative charge, it can be easily accelerated with an electric field. The photodetachment of Ps^- to neutral Ps after the acceleration produces an energy-tunable Ps beam [6, 7]. In order to photodetach Ps^-, which has a short lifetime (479 ps), it must be irradiated with a high-power pulsed YAG laser light synchronized with the production of Ps^-. The linac based beam at the Slow Positron Facility is suitable for this purpose.

Since Ps has negative affinity for most materials, the beam will be useful for analyzing the topmost layers of solids. Furthermore, the beam is not influenced by the charge-up of surfaces even if it is incident on insulators.

Progress in FY2012: The positrons generated in the short pulse mode were transported in UHV and injected into a Na coated polycrystalline tungsten target. The pulsed Ps^- ions emitted from the target were successfully photodetached in FY2010. Following this, production of an energy tunable Ps beam was confirmed by direct time-of-flight measurement of the beam in FY2011 [8, 9]. In FY2012, the spatial profile of the Ps beam was measured with a position-sensitive MCP. The detailed mechanism of the efficient formation of Ps^- on an alkali metal coated W surface is not yet understood. In order to shed light on this issue, time-of-flight measurement of the Ps emitted from a Na coated W surface was conducted. In contradiction to the expected negligible effect of the Na deposition since Ps is neutral consisting of one electron and one positron, the yield of the Ps increased drastically [10]. This is another interesting surface phenomenon awaiting clarification.

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