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 tantalum (Ta) converter plate, where Bremsstrahlung makes electron–positron pairs. The positrons so produced are moderated using a tungsten (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-tuned 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. The high-energy transport capability is unique among the world's high-intensity positron beam facilities.

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.

The locations of the experimental stations were not changed in FY2013. The beamline branches currently available and the connected stations are summarized below:

[Test Hall]

SPF-A3: total-reflection high-energy positron diffraction (TRHEPD)

[Klystron Gallery Lab]

SPF-B1: photodetachment of positronium negative ion (Ps^-)

SPF-B2: positronium time-of-flight (Ps-TOF)

4-2 Projects

Two projects are running in connection with the activity of the Slow Positron Facility.

[1] 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))

Low-energy positron diffraction (LEPD) and total-reflection high-energy positron diffraction (TRHEPD), the positron counterpart of low-energy electron diffraction (LEED) and reflection high-energy electron diffraction (RHEED), respectively, are being developed for surface structure analysis. TRHEPD is a new name of the method formerly called reflection high-energy positron diffraction (RHEPD). Positron diffractions are easier to interpret than electron diffractions because: concerning LEPD, (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, and (3) the scattering factor for the positron falls off smoothly like that of X-rays and its angular dependence is also as simple as that of X-rays because a positron is repelled by the nuclei and does not have a bound state. Concerning TRHEPD, (4) the total reflection takes place owing to the positive electrostatic crystal potential of all the materials.

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 a laboratory. This project solves this problem by making use of a high-intensity slow-positron beam created by using the linac of the Slow Positron Facility and enhancing its brightness.

The extremely high sensitivity of the positron diffraction to the surface makes it possible to determine the details of the surface atomic configurations which are not easily done by X-ray or electron diffraction or a scanning tunneling microscope (STM). Direct determination of the surface atomic geometry will be attempted in two ways: by analyzing the TRHEPD 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 FY2013) The structure of a silicene sheet on Ag(111) has been determined by using TRHEPD for the first time [3] by using the brightness enhanced beam on beamline SPF-A3. A new beamline branch for the LEPD station to be installed soon has been constructed; it will be called beamline SPF-A4. At the upstream of the beamline before the first branch, a pulse-stretch section has been planned. The purpose of this section is to address the following difficulties: the number of positrons within a single pulse is so large that the Doppler broadening of the annihilation γ-rays using a Ge detector cannot be measured because the signals pile up. Also, it is too large for the delay line detector for the planned LEPD measurements.

[2] 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 at 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. It 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 positronium will be a powerful tool in the investigation of material surfaces. However, the production of a beam with sufficient intensity and appropriate energy range was difficult to realize. The only beam of positronium produced before this project started was produced using charge exchange between positrons and gas molecules in the energy range below 400 eV.

This project aims to produce an energy-tunable positronium beam by employing photodetachment of the positronium negative ion (Ps^-), a bound state of two electrons and a positron, in an ultra-high-vacuum environment. Recently, Nagashima et al. found that the Ps^- is emitted efficiently from alkali metal-coated tungsten surfaces when bombarded with slow positrons [4]. 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 makes an energy-tunable Ps beam [5,6]. In order to photodetach Ps^-, which has a short lifetime (479 ps), it must be irradiated with high-power pulsed YAG laser light. The linac-based beam at the Slow Positron Facility is suitable for the production of Ps^- synchronized to the laser pulses. The beam will demonstrate its power for analyzing the topmost layers of solids because positronium has negative affinity for most materials. Furthermore, the beam is not influenced by the charge-up of surfaces even if it is incident on insulators.

In the present project, investigation of the Ps^- photodetachment processes is also planned. The cross sections have been calculated and resonances for the Ps^- photodetachment have been predicted. Experimental studies on the photodetachment are important not only for basic science but also for efficient production of the energy-tunable Ps beam.

(Progress in FY2013) The energy-tunable Ps beam apparatus was completed and its spatial profile was measured in FY2012. In FY2013, the Ps beam apparatus was employed to investigate the Ps^- photodetachment resonances. 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 irradiated with UV pulses from a dye-laser and the Ps atoms formed through the Ps^- photodetachment were detected using a MCP. Preliminary data indicating the Ps^- resonance have been obtained.

In order to investigate the effect of alkali metal coating, time-of-flight of the Ps emitted from the Na-coated W surface was measured in FY2012. In FY2013, time-of-flight of the Ps emitted from Cs- and K-coated W was measured. The data show that the Ps yield increased drastically as in the case of Na coating. Furthermore, a low-energy component, which was not observed for the Na-coated surface, appeared by Cs and K coating. This is another interesting surface phenomenon waiting to be understood.

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