Production of an Energy-Tunable Positronium Beam

An energy-tunable positronium beam has been successfully produced in the KEK Slow Positron Facility by using photodetachment of the positronium negative ion, a bound state of one positron and two electrons. The ions were generated efficiently by bombarding a Na-coated tungsten surface with a pulsed slow positron beam in the short pulse operation mode of the dedicated 55-MeV linac. The ions were then accelerated using a static electric field, and pulsed laser light with a high photon density sufficient for the photodetachment was irradiated. A positronium beam with a hitherto unrealized energy range of up to 1.9 keV was produced in an ultrahigh vacuum environment.

Positronium (Ps), a bound state of one positron and one electron, is a pure leptonic atom. Due to the neutrality and small mass of Ps, an energy-tunable beam of Ps is expected to be a powerful tool for investigations of atoms, molecules, and solid surface structures.

Ps atoms can be formed when slow positrons collide with solid surfaces or gas molecules. The maximum emission energy of Ps atoms from solid surfaces is a few eV and these neutral Ps atoms cannot be accelerated to the desired energy after formation. Thus, the only energy-tunable beam developed so far has been based on the charge exchange reaction of energetic positrons with gas molecules, where the beam energy is controlled by changing the incident positrons. The Ps energy range of such a beam is limited to below 400 eV and it is difficult to obtain ultrahigh vacuum conditions.

It has been expected that an energy-tunable Ps beam could be produced by employing the photodetachment of accelerated positronium negative ions (Ps^-).

We reported the first successful photodetachment of Ps^- in FY2010 [1, 2]. In the present work, we succeeded in producing an energy-tunable Ps beam using the Ps^- photodetachment technique [3].

The Ps^- ions were generated efficiently on a Na-coated tungsten target in back-reflection geometry using a pulsed slow positron beam at the KEK-IMSS Slow Positron Facility [4]. The 55-MeV electron linac was operated in a short pulse mode. The positrons were guided by an axial magnetic field with a transport energy of 4.2 keV (Fig. 1). The beam was deflected by 45º along a curved magnetic field and was incident onto the target through an electric-field-free region between two grids, A and B, biased at 2.8 kV.

The target was a polycrystalline tungsten foil of 25 µm thickness. It was annealed in situ at 1800 K for 30 min. After cooling down to room temperature, one monolayer of Na was deposited in order to obtain high Ps^- emission efficiency [5].

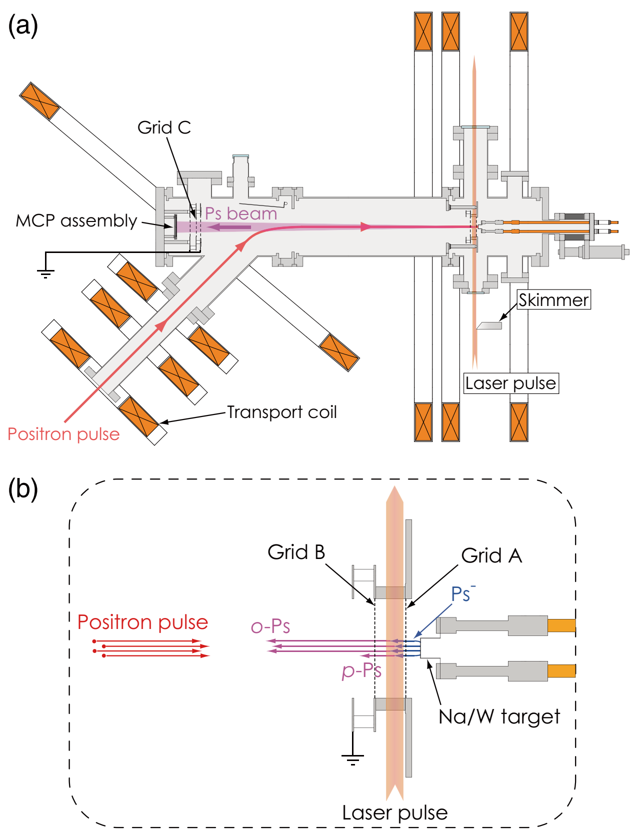

Figure 1
Schematic diagram of the Ps beam system. Reprinted with permission from *Applied Physics Letters* **100** (2012) 254102. Copyright American Institute of Physics (2012).

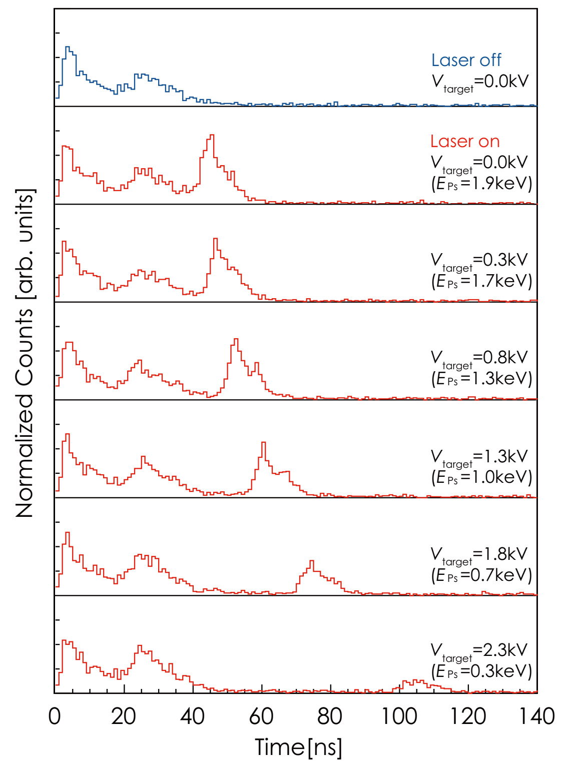

Figure 2
TOF spectra of the o-Ps atoms formed by the photodetachment of Ps^- ions. E_{Ps} is the Ps energy calculated from V_{target}. Reprinted with permission from *Applied Physics Letters* **100** (2012) 254102. Copyright American Institute of Physics (2012).

The target bias, V_{target}, was varied from 0 to 2.3 kV. The Ps^- ions emitted from the target were accelerated by the potential difference between grid A and the target. They were photodetached in the field-free region by an infrared laser light from a Q-switched Nd:YAG laser. The photon energy was 1.165 eV, which is higher than the photodetachment threshold. The orthopositronium (o-Ps) atoms formed by the photodetachment were detected using a micro-channel plate (MCP) assembly placed 80 cm downstream from the target. The time-of-flight (TOF) spectra of the o-Ps atoms were accumulated using a digital oscilloscope.

Figure 2 shows the obtained TOF spectra. Two peaks appear without laser irradiation. They do not change while the laser is on and are independent of V_{target}. While laser is on, the third peak appears; it is attributed to neutral o-Ps atoms detected by the MCP assembly. The TOF, *t*, of o-Ps can be expressed as

$$t = L\sqrt{\frac{3m_e}{2e\left(V_{grid}-V_{target}\right)}}, \qquad (1)$$

where *L* is the o-Ps flight distance, V_{grid} is the potential of the field-free region (2.8 kV), and m_e is the rest mass of the electron and the positron. The TOF of the third peak in Fig. 2 is consistent with Eq. (1).

The present Ps beam provides a hitherto unachieved energy range extending up to 1.9 keV. The advantages of the present method include the simultaneous attainment of high energy and ultrahigh vacuum compatibility, thus enabling the analysis of clean surfaces of solids. This successful production of an energy-tunable Ps beam paves the way to a new era of investigations of solid surfaces, such as reflection high-energy Ps diffraction and Ps scattering experiments.

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Y. Nagashima (Tokyo Univ. of Science)