

Positronium and positronium negative ion emission from alkali-metal coated tungsten surfaces

Y Nagashima¹, K Michishio¹, H Terabe¹, R H Suzuki¹, S Iida¹, T Yamashita¹, R Kimura¹, T Tachibana², I Mochizuki³, K Wada³, A Yagishita³ and T Hyodo³

¹ Department of Physics, Tokyo University of Science, 1-3 Kagurazaka, Shinjuku, Tokyo 162-8601, Japan

² Department of Physics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima, Tokyo 171-8501, Japan

³ Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

E-mail: ynaga@rs.kagu.tus.ac.jp

Abstract. The emission efficiencies of positronium atoms and positronium negative ions from tungsten surfaces increase by alkali-metal coating. We have studied the positronium emission from alkali-metal coated surfaces using the positronium time-of-flight method. We have also performed the observation of the photodetachment of Ps^- emitted from a Na-coated surface and the production of an energy-tunable Ps beam employing the photodetachment technique. This paper describes our recent studies using alkali-metal coated surfaces.

1. Introduction

Recently, we found that the efficiency for the emission of the positronium negative ion (Ps^-), a bound state of one positron and two electrons [1], from tungsten surfaces bombarded with slow positrons increases by coating the surfaces with alkali-metals [2, 3]. This method has been applied for the observation of Ps^- photodetachment [4] and the production of an energy-tunable positronium (Ps) beam employing the photodetachment technique [5]. The emission efficiency of neutral Ps atoms also increases by coating the surfaces with alkali-metals. In order to investigate Ps emission from alkali-metal coated surfaces, we have started the measurements of the time-of-flight (TOF) of Ps emitted from alkali-metal coated surfaces [6].

In this paper, we will review our recent experiments on Ps and Ps^- emitted from alkali-metal coated tungsten surfaces.

2. Ps emission from alkali-metal coated surfaces

Figure 1 shows the annihilation γ -ray energy spectra that indicate the emission of Ps^- from clean and Na-coated tungsten surfaces. The Ps^- ions emitted from the surfaces were accelerated by an electric field applied in front of the surface and the blue-shifted γ -rays emitted from the self-annihilation of Ps^- were detected using a Ge detector [3]. The electric field forced re-emitted positrons to accelerate back towards the surface. While the peak in the spectrum at 529 keV, which indicates Ps^- emission, becomes higher by the coating, the peak at 511 keV becomes lower.



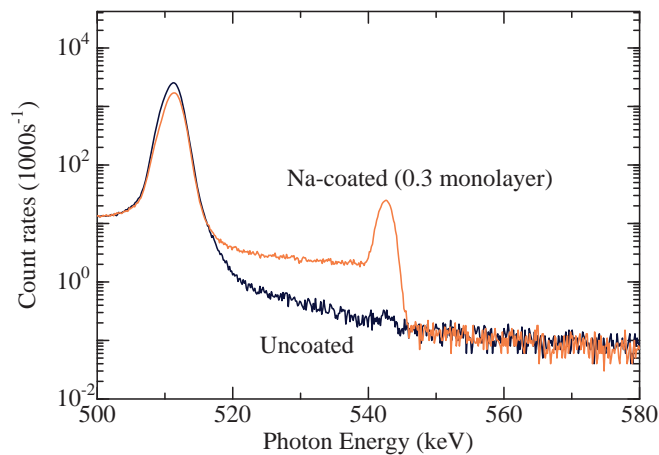


Figure 1. Annihilation γ -ray energy spectra for the Ps^- emission from uncoated and Na-coated polycrystalline tungsten surfaces [3].

This shows that the fraction of ortho- Ps , which self-annihilates into three γ -rays, increases by the coating.

The change in Ps yield by alkali-metal coating was investigated by Mills [7], Gidley *et al* [8] and Fazleev *et al* [9]. The increase in the Ps yield was attributed to a change in activation energy for the emission of Ps atoms formed from positrons trapped by the image potential at the surface. The activation energy for this process can be formulated as

$$E_a = E_b + \phi_- - 6.8\text{eV}, \quad (1)$$

where E_b is the binding energy of the positrons at the surface. The value of ϕ_- is reduced by the coating and hence E_a becomes lower and causes the positrons trapped at the surface to desorb as Ps . The emission energy of the Ps formed by this process should be lower than the emission energy of Ps formed from delocalized positrons, which can be formulated as

$$E_{\text{Ps}} = -\phi_+ - \phi_- + 6.8\text{eV}, \quad (2)$$

where ϕ_+ is the positron work function.

In order to investigate the Ps formation process, we measured the TOF of Ps emitted from a Na-coated tungsten surface [6]. A pulsed slow positron beam generated at the beam dump of an electron linac at the KEK-IMSS Slow Positron Facility [10] was incident onto the surface and the time interval between the linac pulse signal and the detection through a lead slit of the γ -rays from the o- Ps was measured [6]. The resulting TOF data are shown in figure 2. It shows that the component of the Ps emitted with E_{Ps} increases by the coating. This increase may be due to a reduction in the conduction electron density near the surface to a point suitable for the Ps formation [11, 12].

Further systematic measurements of Ps emission energy from tungsten surfaces coated with other alkali-metals are being conducted. A preliminary measurements using a Cs-coated tungsten surface shows that the yield of the lower energy component also increases.

3. Ps^- emission from alkali-metal coated surfaces

The enhancement of the Ps^- emission efficiencies by alkali-metal coating is attributed to a reduction in the surface dipole barrier, which results in an increase in the number of conduction electrons contributing to the Ps^- formation. This enhancement may also be due to the reduction in the conduction electron density near the surface to a point suitable for the Ps^- formation [11, 12].

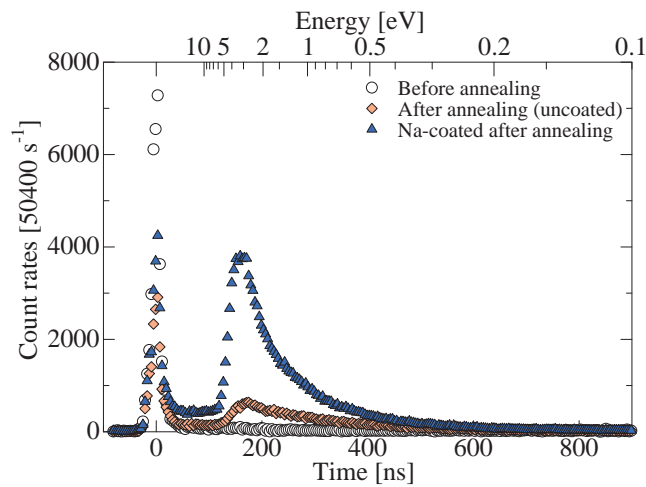


Figure 2. Time-of-flight spectra for clean and Na-coated polycrystalline surfaces [6].

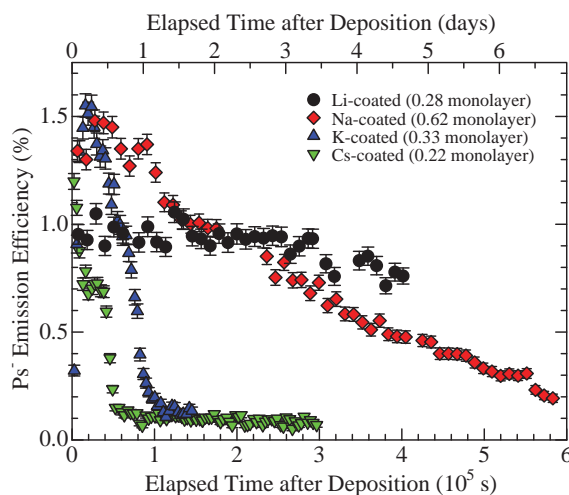


Figure 3. Ps^- emission efficiencies from Cs, K, Na and Li-coated tungsten surfaces plotted against time elapsed after the deposition.

Since alkali-metals are chemically reactive, the Ps^- emission efficiency decreases with the time elapsed after the coating, even in ultra-high vacuum conditions [2, 3]. In the case of Cs-coating, the efficiencies yield decreases to 1/10 of the maximum value in half a day. The efficiency for Na-coated surfaces is more durable than for Cs-coated surfaces because Na is less reactive than Cs. The efficiency reached a maximum value of 1.5 % after 4×10^4 s and decreased to 0.5 % after 4 days.

We have also measured the efficiency from a Li-coated polycrystalline surface. The thickness was 0.3 monolayer, which is slightly thinner than the thickness for which the electron work function is minimum. The results are plotted in figure 3. Although the maximum efficiency was lower than those for other alkali-metals, the efficiency remained almost constant for 3×10^5 s after the coating.

4. Production of an energy-tunable Ps^- beam using the Ps^- photodetachment technique

Recently, an experimental study for the observation of Ps^- photodetachment was performed using Ps^- emitted from a Na-coated tungsten surface [4]. We have also performed the production of an energy-tunable Ps^- beam employing the photodetachment technique [5].

A high-power pulsed laser light is required for Ps^- photodetachment because the Ps^- lifetime

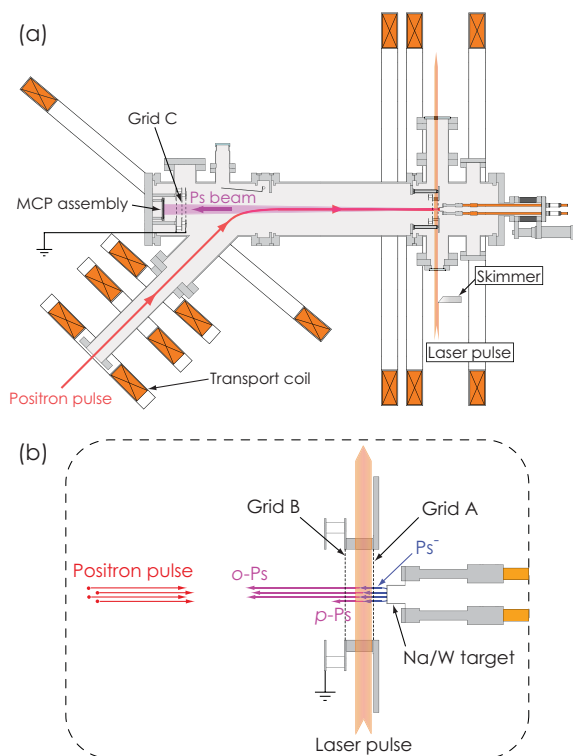


Figure 4. Schematic diagram of the energy-tunable Ps beam developed using the Ps⁻ photodetachment technique [5].

is as short as 479 ps. Thus a pulsed slow positron beam synchronized to the laser is also required. In this study, a pulsed slow positron beam generated at the beam dump of an electron linac at the KEK-IMSS Slow Positron Facility [10] was transported to a Na-coated polycrystalline tungsten target. The emitted Ps⁻ ions were accelerated by an electric field between the target and a grid located in front of the target and were then photodetached using the fundamental wave of Q-switched Nd:YAG laser (figure 4). The formed Ps atoms were detected by a micro-channel plate (MCP) located 80 cm downstream of the photodetachment region. The linac trigger pulses and the signals from the MCP were recorded using a digital oscilloscope.

The TOF spectra of Ps formed by the photodetachment are shown in figure 5. The peaks at $t = 0$ are due to the detection of the γ -rays emitted from positron annihilation at the target by the MCP and the peaks at $t \sim 25$ ns are attributed to the γ -rays emitted from positron annihilation at the chamber wall of back scattered positrons from the target. When the laser is on, another peak appears, which is due to the detection of energetic Ps produced by the photodetachment. The TOF varies by changing the Ps⁻ acceleration potential. This means that an energy-tunable Ps beam is produced and the Ps kinetic energy is controlled by the Ps⁻ acceleration. We have also observed the Ps beam spot using a position sensitive detector with delay-line anodes. The details of this work will be published elsewhere [13].

5. Future plans

Resonances of the photodetachment of H⁻, a three-body system similar to Ps⁻, have been observed [14]. Theoretical studies on resonances in the Ps⁻ photodetachment have also been performed and the energies and the cross sections have been predicted [15, 16, 17, 18]. We are planning experiments to observe the resonances.

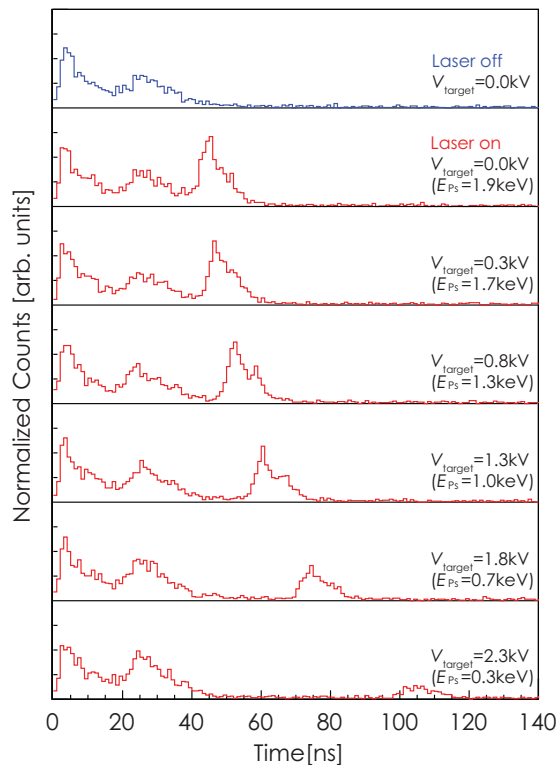


Figure 5. TOF spectra of the Ps produced by the photodetachment of Ps^- accelerated by an electric field [5].

The Ps beam may be applied for surface sciences. Recently, experimental studies on the diffraction of fast atomic projectiles during grazing scattering from surfaces have been performed [20, 21, 22]. Ps has been predicted to be an ideal probe for surfaces because the affinities for most materials are negative and hence information regarding the topmost atomic layers can be obtained [19]. We will attempt to observe reflected high-energy Ps diffraction (RHEPsD).

We also plan to produce an energy-tunable Ps beam using a pulsed positron beam extracted from a buffer-gas positron trap (Surko trap). Figure 6 shows the schematic diagram of the new Ps beam apparatus. Ps^- ions emitted from an alkali-metal coated surface opposite to the source of a tungsten thin film will be accelerated and photodetached to obtain Ps beams with energies greater than 5 keV. Another advantage of this geometry is that the length of the Ps flight path can be reduced and hence the beam spot size at the sample can be smaller. The apparatus is compact and can be used in a typical university laboratory.

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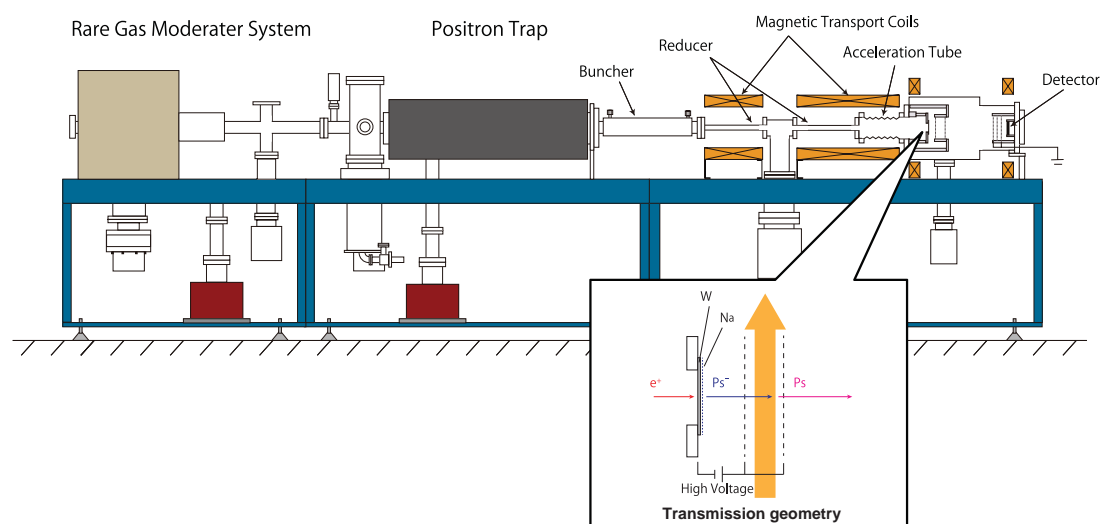


Figure 6. Conceptual design of the energy-tunable Ps beam using a buffer gas positron trap (Surko trap).

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