Efficient emission of positronium atoms from an Na-coated polycrystalline tungsten surface

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Abstract. Time-of-flight spectra for the ortho-positronium emitted from clean and Na-coated tungsten surfaces have been measured using the pulsed slow positron beam at KEK-IMSS slow positron facility. Emission efficiency of positronium from the Na-coated sample was found to be several times greater than that from uncoated tungsten surfaces.

1. Introduction
Recently, we reported that the emission efficiency of positronium negative ions (Ps\(^-\)) from tungsten surfaces bombarded with slow positrons was enhanced by alkali-metal coating [1, 2]. This enhancement is thought to be due to the surface dipole barrier reduction by alkali-metal deposition, which results in the increase in the fraction of conduction electrons available for the Ps\(^-\) emission.

The \(\gamma\)-ray energy spectra for the investigation of Ps\(^-\) emission indicated that the positronium (Ps) yields also increase by the coating. The Ps emission energy, \(T_{Ps}\), from the surface is expressed as

\[
T_{Ps} = -\phi_+ - \phi_- + E_B,
\]

where \(\phi_+\) and \(\phi_-\) are the positron and electron work functions, respectively, and \(E_B\) is the Ps binding energy (6.8 eV). The values of positron and electron work functions for the surface with alkali-metal coating can be written as

\[
\phi'_+ = \phi_+ + \Delta \quad \text{and} \quad \phi'_- = \phi_- - \Delta,
\]

where \(\Delta\) is the effect of surface dipole barrier reduction by the coating. Therefore, the emission energy for the Ps emission is unchanged by the coating.

In the present work, we have measured the energy distribution of ortho-positronium (\(\alpha\)-Ps) emitted from Na-coated tungsten surface using a time-of-flight (TOF) technique in order to investigate the mechanism of Ps emission.
2. Experimental Procedure
The measurements were performed using a pulsed slow positron beam at the KEK-IMSS slow positron facility [3]. Positrons were generated by a 55 MeV electron linac operated in a short pulse mode and moderated using a tungsten moderator. The repetition rate of the linac was 50 Hz. The pulsed slow positron beam was magnetically transported after being accelerated to an energy of 4.2 keV in order to minimize pulse widening. The pulse width near the target was 10 ns.

Figure 1 shows the schematic diagram of the measurement system. The base pressure of the target chamber was $6 \times 10^{-8}$ Pa. The target was a polycrystalline tungsten foil of 25 µm thick. It was annealed in situ at 1800 K for 30 min by the passage of an electric current. After being cooled down to room temperature, Na atoms were deposited. The thickness of the Na coverage was 2.6 Å, where the electron work function has been reported to be the lowest [4]. The target was grounded and the positron incident energy was 4.2 keV.

Two plastic scintillation detectors can be installed to detect the $\gamma$-rays. Only the detector located 120 mm from the target was used in this measurement. The scintillator was 100 mm $\times$ 100 mm square and 10 mm in thickness and coupled on opposite side to a photomultiplier tube (HAMAMATSU H6614) by a light guide. The $\gamma$-rays were detected through a lead slit of 6 mm width. The time resolution of this measurement system including the beam pulse width was 10 ns, which was better than that used for the TOF measurement of $\sigma$-Ps emitted from SiO$_2$ [5]. The time intervals between the linac pulses and the signals from $\sigma$-Ps self-annihilation were measured using a digital oscilloscope with a sampling speed of 500 MS/s. The waveform data were transferred to a PC and then TOF spectra were obtained off-line.
Figure 2. TOF Spectra for unannealed, annealed and Na-coated W surfaces.

3. Results and Discussion

Figure 2 shows the obtained TOF spectra for unannealed, annealed and Na-coated samples. The spectra were normalized to the measurement time. Large peaks near time zero are attributed to the prompt annihilation of the positrons in the target and self-annihilation of para-positronium. The peak becomes higher by the coating. This indicates that the fraction of re-emitted slow positrons becomes lower by changing $\phi_+$. The spectra show that the yield of o-Ps component increases by Na coating. For the annealed and Na-coated samples, the components appear after about 120 ns. It corresponds to the energy of 5 eV, which agrees with the Ps emission energy calculated using equation (1) and reported values of $\phi_+$ and $\phi_-$ for polycrystalline tungsten [6, 7]. This indicates that the maximum energy of Ps emission is independent of Na coating as expected.

Mills [8] and Gidley et al. [9] suggested that the positrons bound in their image potential well at the surface may be emitted as Ps atoms by lowering $\phi_-$ when the surface is coated with alkali-metal. According to this model, the yield of lower energy component of o-Ps in the TOF spectrum should increase. However, figure 2 shows that the yield of higher energy component increases further and the shape of the o-Ps energy distribution becomes narrower than that for the uncoated surface.

Acknowledgments

We thank K. Michishio, R. H. Suzuki, T. Shidara, S. Osawa, M. Ikeda and other KEK staff for their generous support for the positron beam line. This work has been performed under the approval of the Photon Factory Program Advisory Committee (Proposal No. 2010S2-003). It was partly supported by a Grant-in-Aid for Scientific Research (No. 24221006) from the Ministry of Education, Science and Culture of Japan.

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