Outlook of the KEK-IMSS Slow Positron Facility

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The Slow Positron Facility at KEK IMMS is equipped with a dedicated 55 MeV linac, providing a high-intensity, pulsed slow-positron beam [1]. The beam is produced in a production unit at a high tension of up to 35 kV and guided magnetically through a grounded beam line, and then branched.

The main research projects of the Facility in the immediate future are related with the following grants:

(1) Grant-in-aid for Scientific Research <Kakenhi> Scientific Research (S) "Development of High-brightness and High-intensity Positron Diffraction and its Application to Surface Studies"

(2) Grant-in-aid for Scientific Research <Kakenhi> Scientific Research (S) "Evolution of the positronium beam science using the technique of photodetachment of the positronium negative ion"

The former makes use of the high intensity of the beam. The latter makes use of the 10ns pulse of the beam as well as the high intensity.

It is known that positron diffraction is extremely sensitive to solid surfaces [2]. Compared with electron and X-ray diffractions, the positron diffraction has several advantages. For example, surface sensitivity is highest because inelastic scattering cross section is large; it is totally reflected from a solid surface for a glancing angle smaller than a certain critical angle depending on the sample material and the energy of the incident positron beam because the crystal potential for a positron is positive; the angular dependence of the scattering factor for positrons is as smooth as for X-rays and much simpler than for electrons; interactions of a positron with inner-core orbital electrons are small and thus the treatment of the interactions is simple since a positron is not attracted by nuclei. The simplicity of the analysis makes accurate comparison with experiments possible. Obvious weakness of the positron is that it is an anti-particle that it is not easy to get a beam strong enough. This last drawback is resolved by doing experiments at KEK.

Low energy positron diffraction (LEPD) is the positron version of low energy electron diffraction (LEED) and has a history of 30 years. The concept design of a LEPD setup for the Facility is just started. The setup will be completed in 2013.

Reflection high-energy positron reflection (RHEPD) is the positron version of reflection high-energy electron diffraction (RHEED). RHEPD was proposed by Ichimiya [3] and realized by Kawasuso and Okada [4] at JAEA, Takasaki, using a ^{22}Na-based positron beam. Their measurement chamber for RHEPD has been transferred to KEK to be operated with a high intensity, brightness-enhanced beam, resulting in 63 time increase in intensity and a few thousand time enhancement of the brightness. This means 63 time improvement of the data acquisition efficiency and much higher quality of the data. An improved station for RHEPD is being designed and will be installed by April 2013.

We expect that the positron diffraction will be especially useful for the structural analysis of solid surfaces where heavy elements are involved, such as those of topological insulators and Rashba surfaces.

We will attempt direct analysis of the surfaces using Patterson analysis of positron holography.

The second project was initiated by a development of a method for an efficient production of positronium negative ion by Nagashima [4]. By combining the positronium negative ion production by the pulsed positron beam at KEK with a synchronized high intensity Nd:YAG laser, both pulse width 10ns, photodetachment of the ion into neutral positronium atom and an electron was accomplished [5]. This process combined with variable electrostatic acceleration of the negative ion provide a method for the production of an energy-tunable positronium beam [6]. After refinement of the quality of the beam, its application to materials science will follow. Examples are positronium reflection from solid surfaces, reflection high-energy positronium diffraction, and fundamental researches on positronium and its negative ion.

In order to make the Facility available for a wider variety of measurements, a linear storage of the positron beam to transform it to continuous beam will be installed. Then the beam will be used for the analysis of the annihilation γ-rays as in coincidence Doppler broadening measurements.

Rebunching the beam to make it short pulsed suitable for the positron lifetime measurements will also follow.

Further ten time increase in the intensity of the beam is possible if we move the linac to the next door space; the present location of the linac is too narrow to make enough radiation shields for higher intensity.

References:

[1] K. Wada, T. Hyodo, A. Yagishita, et al., *Eur. Phys. J. D* **66** (2012) 37.
[1] S. Y. Tong, *Surf. Sci.* **457** (2000) L432.
[2] A. Ichimiya, *Solid State Phenom,* **28/29** (1992) 143.
[3] K. Kawasuso and S. Okada, *Phys. Rev. Lett.* **81** (998) 2695.
[4] Y. Nagashima et al., *New J. Phys.* **10** (2998) 123029.
[5] K. Michishio, T. Tachibana, H. Terabe et al., *Phys. Rev. Lett.* **106** (2011) 153401 .
[6] K. Michishio, T. Tachibana, R.H. Suzuki et al., *Appl. Phys. Lett.* **100** (2012) 254102.

Main Research Projects

Projects of Grant in Aid for Scientific Research (S)

1. "Development of High-brightness and High-intensity Positron Diffraction and its Application to Surface Studies"
   (project leader: T. Hyodo)
   → all the experiments conducted in KEK

2. "Evolution of the positronium beam science using the technique of photodetachment of the positronium negative ion"
   (Project leader: Y. Nagahisma)
   → part of experiments conducted in KEK

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Main Project 1

"Development of High-brightness and High-intensity Positron Diffraction and its Application to Surface Studies"

High-intensity slow positron beam (KEK) → Brightness Enhance-ment → Low-energy positron diffraction(LEPD) Reflection high-energy positron diffraction (RHEPD)

RHEPD: leading the world → better with brightness enhancement
LEPD : starting with higher brightness than others
→ hope catching up soon and leading the others

(1)Structure analysis of surfaces where heavy elements are involved (topological insulator, giant Rshba surface)

(2)Direct determination of the structures (Patterson analysis with RHEPD; positron hollography with LEPD)

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Superiority of positron diffractions

Precise determination of the surface atomic arrangement is the key to surface science.

The positron is the most sensitive to the surface structure.

Comparison of 3 Beams (e: excellent, g: good, p:poor)

Characteristics	e^+	e^-	X-rays	Notes on e^+
Surface sensitivity	e	g	p	inelastically scattered easily
Information of the topmost layer through total reflection	e	–	p	positive crystal potential
Easiness in high precision analysis	g	p	e	scattering factor as simple as for X-rays
Analysis of the position of heavy elements	e	p	g	not attracted by nuclei
Intensity	p	g	g	anti-particle

ideal

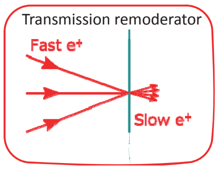
Resolved by using high intensity beam at KEK

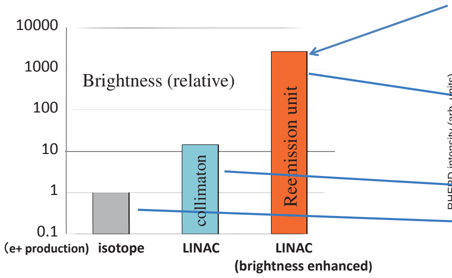
Brightness Enhancement by Remoderation

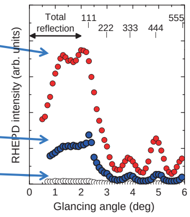
輝度

$$B = \frac{I}{\pi r^2 E \sin^2\theta}$$

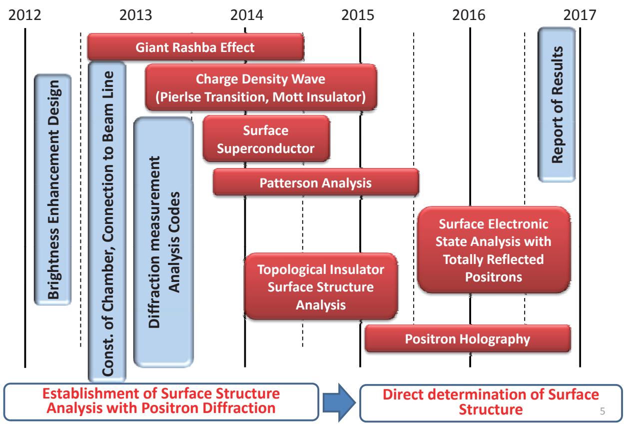
I : beam intensity (→ /10)
: beam radius (→)
: beam energy(5keV→1eV)
θ : beam divergence angle (∼50° → ∼10°)







Positron Diffraction Schedule



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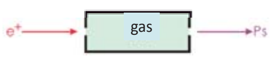
Main Project 2

Positronium Science with Photodetachment of Positronium Negative Ions

Ps beam production so far

Ps, electrically neutral, cannot be accelerated with electric field
Use of molecular scattering with a positron
e^+ + M → Ps + M^+

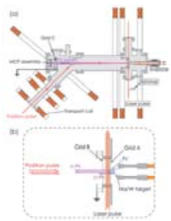


Intensity is low.
Incompatible with ultra high bacuum
Limited to the energy range lower than 100 eV

Ps Beam Production with Ps^-

Accelate Ps^- ions and the photodetach them to produce Energy-tunable Ps Beam

- Higher intensity available
- Compatible with ultra-high vacuum
- Beam with energy higher than 1 keV available



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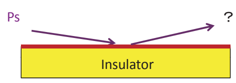
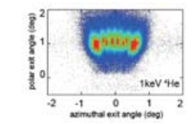
Applications of Energy-tunable Ps Beam

1. Ps reflection from insulator surfaces



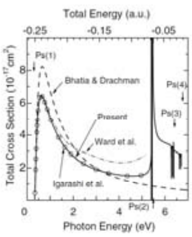
2. Reflected High Energy Ps Diffraction (RHEPsD)



Fast atomic beam diffraction from solid surface

Attempts to get Ps diffraction image

3. Fundamental researches on Ps and Ps^-



- Ps^- photodetachment
- Ps^--periodic feld interactions
- Ps excited states

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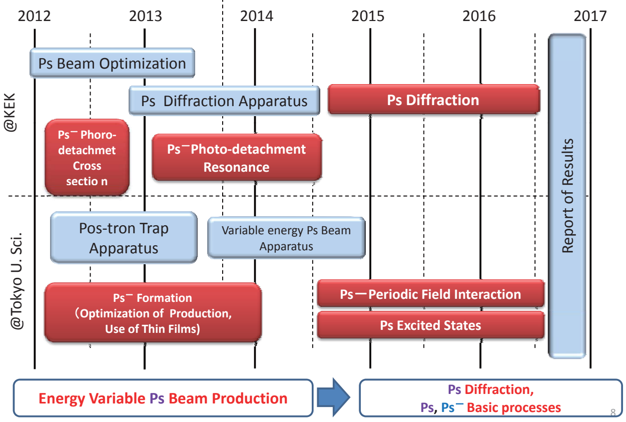
Ps Negative Ion Schedule



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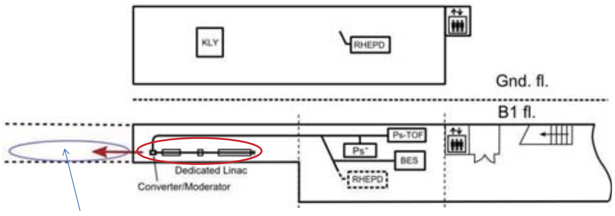
Plans for Other Beam Line Branches

- Construction of Linear Trap for DC Beam
  - Pulse / DC beam both available
  - Doppler Broadening Station
  - Coincidence Doppler Broadening Station
- Construction of short pulse Section
  - Positron Lifetime Station
  - Angular Correlation of Annihilation Radiation Station

10-fold Increase in Intensity

Even 10 more time increse posible → 5×10^8 slow e+/s

Enhanced Linac Power and Sufficient Shield
→ Relocate the Dedicated Linac to Next Door Space



Possible Linac Relocation