

# KEK-PF SLOW-POSITRON FACILITY

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## Abstract

A slow-positron facility, aiming at the use of slow-positron beams (ranging from eV to keV) in various fields of solid-state physics, was constructed utilizing the 2.5-GeV electron linac at the Photon Factory, KEK (KEK-PF) as its primary beam source. The KEK-PF slow-positron source comprises a beam line for the primary electron beam, a target-moderator assembly for positron production, a slow-positron beam-transport line and relevant assemblies. We expect a slow-positron intensity of more than  $2 \times 10^9$  e<sup>+</sup>/s with a maximum primary beam power of 30 kW. Since we achieved an intensity of  $10^8$  e<sup>+</sup>/s with a nominal primary beam power of 2 kW, we opened this facility to slow-positron users.

## Introduction

A positron beam is a useful probe for investigating the electronic states in solids, especially concerning the surface states. The advantage of utilizing positron beams is in their simpler interactions with matter, owing to the absence of any exchange forces, in contrast to the case of low-energy electrons.

However, such studies as low-energy positron diffraction, positron microscopy and positronium spectroscopy, which require high-intensity slow-positron beams, are very limited due to the poor intensity obtained from a conventional radioactive-isotope-based positron source. In conventional laboratories, the slow-positron intensity is restricted to  $10^6$  e<sup>+</sup>/s due to the strength of the available radioactive source.

An accelerator-based slow-positron source is a good candidate for increasing the slow-positron intensity [1-6]. We, therefore, started construction of the KEK-PF slow-positron facility [7,8] from FY1991, aiming to produce more than  $2 \times 10^9$  e<sup>+</sup>/s slow-positrons, utilizing our 2.5-GeV electron linac [9,10] as its primary beam source.

We describe here the KEK-PF slow-positron facility and its performance as well as its recent progress.

## Layout of the KEK-PF Slow-Positron Facility

Figure 1 shows the KEK-PF slow-positron facility, which is located at the end of the KEK 2.5-GeV linac. It comprises a beam line for the primary electron beam, a target-moderator assembly, a slow-positron beam-transport line and relevant assemblies.

The primary electron beam is injected into the target through an achromatic beam-transport line comprising two 18° deflecting magnets and a quadrupole magnet. The nominal beam power of the KEK 2.5-GeV linac is 6.25 kW (an energy of 2.5 GeV, a peak current of 50 mA, a pulse length of 1 μs and a pulse repetition rate of 50 pulse/s), and an

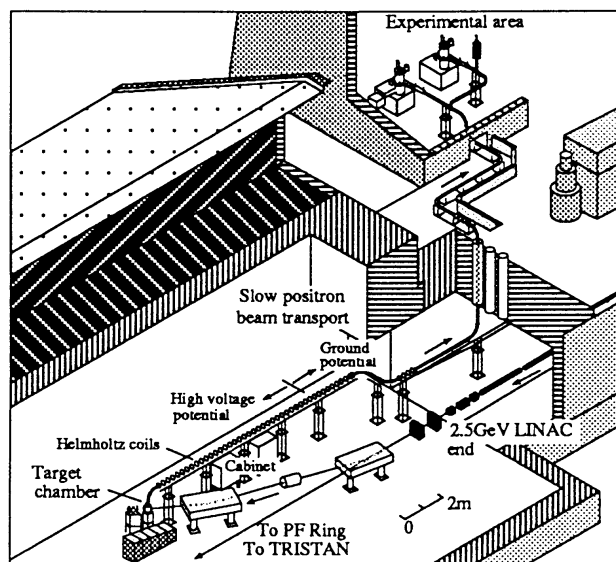


Fig. 1. Bird's-eye view of the KEK-PF slow-positron facility at the end of the KEK 2.5-GeV linac. An achromatic beam-transport line for the primary electron beam and a target-moderator assembly are installed in the under-ground beam switchyard. Slow-positrons are guided through the beam transport to the experimental area at the ground level.

average beam power of 30 kW can be expected from this linac as its maximum beam power [9,10].

The target-moderator assembly comprises a water-cooled tantalum rod of 5 radiation lengths and a moderator with multiple tungsten vanes (thirteen 25-μm thick sheets). The most efficient target thickness for an incident electron energy of 2.5 GeV was decided using the EGS4 Code [11,12]. A maximum slow-positron beam intensity of  $2 \times 10^9$  e<sup>+</sup>/s can be expected with a full beam power of 30 kW, according to the calculated energy spectra of positrons emitted from tantalum targets [13]. Electrostatic focusing grids are located just above the moderator.

The extracted slow-positron beam is directed by a 30-m long beam-transport line with an axial magnetic field of 100 G to an experimental area at the ground level through a 2.5-m thick radiation shield floor. Twenty sets of steering coils were installed along the slow-positron beam-transport line in order to adjust the slow-positron beam trajectory. A high-voltage station capable of applying 60 kV was installed in the initial part of the beam-transport line in order to vary the energy of the positron beam, which is useful for depth-profile measurements. A device controller, combining a personal computer and a programmable sequence controller through

optical fiber, has been adopted to control the monitors and power supplies at a high-voltage potential. Penning-trap electrodes are also installed at this station in order to make a dc beam from a pulsed beam.

At an experimental area, a slow-positron beam switch system, which comprises a pair of beam deflecting coils and two pairs of Helmholtz coils with magnetic-field directions crossing each other (see Fig. 2), was installed. This system enables us to direct slow-positron beams to several experimental stations one by one without breaking the vacuum.

As for the beam monitors, channel-electron multipliers (CEM) for the beam intensity and micro-channel plates (MCP) for the beam profile are intensively used.

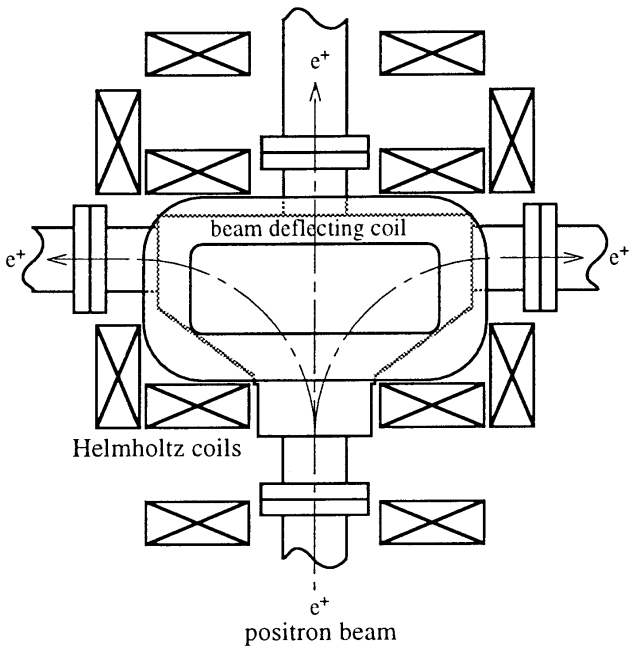


Fig. 2. Schematic view of the slow-positron beam switch system. Two pairs of crossed Helmholtz coils and a pair of deflecting coils direct the slow-positron beam. The deflecting coils are inevitable if one wants to get rid of any unwanted beam offset immediately after a deflection of the slow-positron beam.

### Present Status

At the very initial stage of its performance tests, the observed positron yield was 1/20 of the estimated value [8]. During these tests, the positron intensity at the end of the transport line was estimated by detecting annihilation  $\gamma$ -rays utilizing a BGO scintillator with a photomultiplier tube (HAMAMATSU H2611). This discrepancy was thought to be due to the condition of the moderator, since we put the moderator into the target-moderator chamber without performing any thermal treatment.

An excellent improvement in the positron yield was achieved by annealing of the moderator assembly (tungsten foils) at 2270 K for 10 minutes under ultra-high-vacuum conditions. A slow-positron flux of  $1 \times 10^8$   $e^+/s$  was successfully achieved with a 2.0-GeV, 2-kW primary electron beam power. The achieved conversion efficiency has almost reached our designed goal; we can therefore expect a slow-positron intensity on the order of  $10^9$   $e^+/s$  with a maximum beam power of 30 kW in the near future.

The energy of the positron beam was successfully varied from 400 eV to 40 keV by applying a voltage to the high-voltage station at the initial part of the slow-positron beam-transport line (see Fig. 1). Although radiation from the target chamber, at a kW primary beam operation, caused severe damage to the programmable sequence controller at the high-voltage station (RAM bit error), reinforcement of the radiation shield for the target chamber cured this trouble.

A slow-positron beam with a beam energy of 800 eV was successfully switched from one direction to another utilizing the slow-positron beam-switch system. We can therefore supply slow-positron beams to several experimental stations without any waste of time.

Since we have already achieved a slow-positron intensity of  $10^8$   $e^+/s$  in our facility, we have opened this facility to slow-positron users.

### Positronium Time-of-Flight (TOF) Experiment

As an example experiment at the KEK-PF slow-positron facility, we briefly describe here energy-distribution measurements of the positronium (Ps) emitted from a single-crystal quartz. Ps is known to form in the interior of many insulators with a wide band-gap energy. The energy loss and slowing-down process of positrons in matter is becoming well understood. For positrons with energies of less than the band gap, the production of Ps and phonon excitation become the dominant energy-loss mechanism. To date, very little has been studied about the kinetics of the formation and diffusion of Ps, which is in the state immediately after the production and before its delocalization.

We obtained the energy distribution of Ps by adopting the time-of flight (TOF) method to emitted Ps [14]. The TOF was determined by measuring the time interval between the arrival time of a pulsed-positron beam and the detection of radiated  $\gamma$ -ray from annihilated Ps. Since the lifetime of Ps is well known, we can easily deduce the energy distribution of Ps from the TOF spectra, which were measured by changing the distance between the sample surface and the annihilation  $\gamma$ -ray detector, only if the pulse width of the injected positron beam (20 ns in the present case) is shorter than the lifetime of the Ps.

Figure 3 shows the preliminary result of a positronium TOF spectrum measured with a distance between the sample surface and the  $\gamma$ -ray detector of 135 mm. Two energy peaks are clearly resolved, which correspond to Ps energies of 3.3 and 0.8 eV, respectively. Although the 3.3 eV peak had already been reported by Sferlazzo et al. [15], the 0.8 eV peak was identified for the first time by the present measurements [14]. This 0.8 eV peak might be due to a thermalization process of the Ps.

### arrival time of a pulsed-positron beam

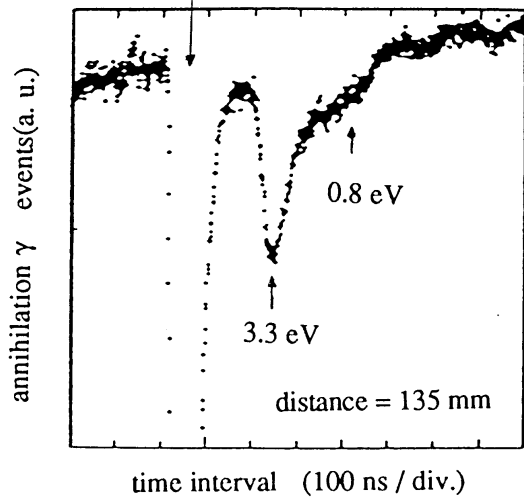


Fig. 3. Positronium (Ps) time-of-flight (TOF) spectrum measured at a distance between the sample surface and the annihilation  $\gamma$ -ray detector of 135 mm.

### Future Plan

The KEK 2.5-GeV linac is now undergoing a reformation process relevant to the KEKB project [16]. There are two major goals of the upgrade [17]: 1) to increase the energy of electrons and positrons to 8 and 3.5 GeV, respectively, and 2) to increase the bunch intensities of positrons by roughly one order. In accordance with this upgrade plan, we must relocate our KEK-PF slow-positron facility to the 1.5-GeV point of the upgraded linac. Although this relocation will take more than one year, there is a possibility to install a dedicated linac for slow-positron use only if we use the remnants of the present 2.5-GeV linac smartly.

### Summary

The KEK-PF slow-positron facility has successfully produced  $10^8$   $e^+$ /s slow positrons with a 2.0-GeV, 2-kW primary electron beam power. The energy of the slow-positron beam was easily varied from 400 eV to 40 keV. This enables us to measure the depth-profile, which is very useful for locating any defects in materials. Slow-positron beams have been smoothly supplied to several experimental stations without breaking the vacuum by the aid of the slow-positron beam switch system. We have opened our slow-positron facility to slow-positron users and several experiments are in progress.

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### References

- [1] R. H. Howell, R. A. Alvarez and M. Stanek, "Production of Slow Positrons with a 100-MeV Electron Linac", *Appl. Phys. Lett.* **40**, p751 (1982).
- [2] R. Ley, K. D. Niebling, A. Osipowicz, A. Picard and G. Werth, *Proc. 7th Int. Conf. on Positron Annihilation*, New Delhi, 1985, eds. P. C. Jain, R. M. Singru and K. P. Gopinathan (World Scientific, Singapore), p996 (1985).
- [3] L. D. Hulett, Jr., T. A. Lewis, D. L. Donohue and A. Pendyala, *Proc. 8th Int. Conf. on Positron Annihilation*, Gent, 1988, eds. L. Dorikens-Vanpraet, M. Dorikens and D. Segers (World Scientific, Singapore), p586 (1989).
- [4] T. Akahane, T. Chiba, N. Shiotani, S. Tanigawa, T. Mikado, R. Suzuki, M. Chiwaki, T. Yamazaki and T. Tomimasu, "Stretching of Slow Positron Pulses Generated with an Electron Linac", *Appl. Phys.* **A51**, p146 (1990).
- [5] R. Suzuki, Y. Kobayashi, T. Mikado, H. Ohgaki, M. Chiwaki and T. Yamazaki, *Proc. 9th Symp. on Accelerator Science and Technology*, Tsukuba, p237 (1993).
- [6] Y. Itoh, M. Hirose, S. Takamura, O. Sueoka, I. Kanazawa, K. Mashiko, A. Ichimiya, Y. Murata, S. Okada, M. Hasegawa and T. Hyodo, "Brightness Enhanced Intense Slow Positron Beam Produced using an Electron Linac", *Nucl. Instr. Meth.*, **A305**, p269 (1991).
- [7] A. Asami, A. Enomoto, H. Kobayashi, T. Kurihara, K. Nakahara and T. Shidara, "A Slow-Positron Source Project using the Photon Factory Electron Linac", *Materials Science Forum*, **105-110**, p1833 (1992).
- [8] T. Shidara, A. Enomoto, T. Kamitani, H. Kobayashi, T. Kurihara, A. Shirakawa, H. Hirayama, I. Kanazawa, A. Asami and K. Nakahara, "The KEK Slow-Positron Source", *Materials Science Forum*, **175-178**, p205 (1995).
- [9] J. Tanaka, "Construction of the Photon Factory 2.5 GeV Injector Electron Linac", *Nucl. Instr. Meth.*, **177**, p101 (1980).
- [10] I. Sato, "Accelerator Structure and Beam Transport System for the KEK Photon Factory Injector", *Nucl. Instr. Meth.*, **177**, p91 (1980).
- [11] W. R. Nelson, H. Hirayama and D. W. O. Rogers, *SLAC-265*, (1985).
- [12] H. Hirayama, *KEK Internal*, **89-17**, (1990).
- [13] H. Hirayama, *Proc. 2nd Workshop on Researches Using Positrons*, Tokyo, 1991 (JAERI Takasaki), p60 (1991).
- [14] Y. Morinaka, Y. Nagashima, T. Hyodo, T. Kurihara, T. Shidara and K. Nakahara, "Positronium Emission from SiO<sub>2</sub> Surface", *Abstract, Autumnal Conf. Phys. Soc. Jpn.*, (1996).
- [15] P. Sferlazzo, S. Berko and K. F. Canter, "Time-of Flight Spectroscopy of Positronium Emission from Quartz and Magnesium Oxide", *Phys. Rev.*, **B35**, p5315 (1987).
- [16] "KEKB B-Facility Design Report", *KEK Report*, **95-7**, (1995).
- [17] eds. I. Sato, S. Anami, A. Enomoto, S. Fukuda, H. Kobayashi and K. Nakahara, "Design Report on PF Injector Upgrade for KEKB", *KEK Report*, **95-18**, (1996).