KEK-IMSS Slow Positron Facility

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Abstract. The Slow Positron Facility at the Institute of Material Structure Science (IMSS) of High Energy Accelerator Research Organization (KEK) is a user dedicated facility with an energy tunable (0.1 - 35 keV) slow positron beam produced by a dedicated 55MeV linac. The present beam line branches have been used for the positronium time-of-flight (Ps-TOF) measurements, the transmission positron microscope (TPM) and the photo-detachment of Ps negative ions (Ps). During the year 2010, a reflection high-energy positron diffraction (RHEPD) measurement station is going to be installed. The slow positron generator (converter/moderator) system will be modified to get a higher slow positron intensity, and a new user-friendly beam line power-supply control and vacuum monitoring system is being developed. Another plan for this year is the transfer of a $^{22}$Na-based slow positron beam from RIKEN. This machine will be used for the continuous slow positron beam applications and for the orientation training of those who are interested in beginning researches with a slow positron beam.

1. Introduction
The slow positron beam at High Energy Accelerator Organization (KEK) started in 1991 sharing the 2.5 GeV electron linac beam with high energy TRISTAN experiments and the synchrotron radiation source for the storage ring of the Photon Factory[1-3]. This beam was used for the positronium time-of-flight (Ps-TOF) measurements, where the linac was operated in a short pulse mode (10ns pulse width and 50 pulses/s at a power of 2 kW. In this experiment the energy distributions of Ps emitted from a SiO$_2$, KI, and MgO single crystals were measured [4]. Overall time resolution of the TOF machine was about 20ns, short enough to measure ortho-positronium time-of-flight whose intrinsic lifetime in vacuum is 142ns. The results showed that Ps is emitted from the SiO$_2$ surface by two mechanisms: emission of Ps formed in the bulk and Ps formation on the surface, with energies 1 and 3 eV, respectively.

Then, in 1997, as a result of the reformation of KEK, Institute of Materials Structure Science was established in KEK, and the Photon Factory became a part of it, and the Slow Positron Facility was formally affiliated to the Photon Factory [5]. At the same time, in conjunction with a new high energy physics experiments called KEKB project, an upgrade of the linac (the KEKB J-linac) aiming at increasing the energy to 8.5 GeV started. As a consequence, the location of the slow positron generator (converter/moderator assembly) was moved to the point where the energy of the accelerated electrons was 1.5 GeV. The linac was operated at a power of 0.75 kW. In addition, because the machine time of the KEKB J-linac available for the slow positron experiments was expected to be
very short, a linac of 55 MeV and 600 W dedicated to the Slow Positron Facility was constructed. It was placed side by side with the KEKB beam line to share the slow positron generator. Unfortunately, however, it suffered from a trouble in cooling water system of the slow positron generator before the dedicated linac became in full operation. It was then realized that the maintenance of the generator system was very difficult as long as it was located near the busy KEKB beam line. Thus in 2001 it was decided to move the dedicated linac to an end of the slow positron experiment hall i.e., the present location [6]. It operates in a short pulse (width 22ns, 2x10^5 e^+/s) and a long pulse (width 1µs, 6x10^6 e^+/s) modes.

2. Present status
The present layout of the branches of the beam line, and the experimental stations are schematically shown in Figure 1. The positronium time-of–flight (Ps-TOF) measurement apparatus was moved to the present experiment hall after a small modification. It has been used for the investigation of the structure of porous materials in collaboration with Mills’ group[7, 8].

In 2005 development of a transmission positron microscope (TPM) by Fujinami group was started. In this machine, the magnetically guided slow positron beam is focused on a transmission-type Ni remoderator for a brightness enhancement, behind which the beam is made free from the magnetic field and guided electrostatically [9]. It has a switch system which makes it possible to observe exactly the same part of the specimen by both the transmission electron microscope (TEM) and TPM. Magnified real space images (up to x10,000) and diffraction patterns of a Au foil observed by the electrons and the positrons have been compared [10].

Another research currently running is photo-detachment of positronium negative ions (Ps'). Nagashima developed a method of creating a high fraction (1%) of Ps’ by bombarding positrons on an alkali metal coated W [11]. It was accomplished with a ^22Na based slow positron beam at his laboratory in Tokyo University of Science. The Ps’ is accelerated by an electric field and blue-shifted annihilation γ-rays from the moving Ps’ give a clear evidence for their existence [12]. The photo-detachment is performed by using the pulsed positron beam (12 ns FWHM, 50 pulses/s) at KEK and an intense photon beam from a Q-switched ND:YAG laser (1 J/pulse at 1064 nm, 12 ns FWHM, 25
pps) synchronized to the positron bunch [13]. Observed reduction of the Doppler shifted Ps’ signal indicates that the Ps’ ions are converted into neutral Ps, of which 3/4 is ortho-Ps which does not annihilate into $2^+$. It is expected that the photo-detachment process will be useful for the production of an energy tunable Ps beam that can be used in UHV environment.

3. Plans for near future

During the year 2010, the converter/moderator at the end of the dedicated linac is going to be renewed, expecting to get better yield of the slow positrons. At present, the high energy electron bombardment on a water cooled Ta target of 4mm thick produces bremsstrahlung photons and the following pair creation. The positrons are then moderated by seven strips of W foils of thickness 25 µm placed perpendicular to the electron beam. The slow positrons are extracted in the direction perpendicular to the incident electron beam. The new version uses 4mm thick Ta for a converter, whose electrostatic potential may be varied from 100 V to 35 kV as the present one. This determines the energy of the slow positrons incident on a grounded sample. The new W moderator foils will be two-fold and each has a honeycomb structure as shown in Figure 2. Electrostatic bias will be applied between the Ta frame and the back W arrangement, between the back and front W arrangements and between the front W arrangement and the extraction mesh electrode. Each bias can be varied independently from 0 to 10 V.

In addition, the control system for the beam line solenoids and Helmholtz coils and the vacuum monitoring system are being revised to make them more user-friendly.

Also two new stations are going to be constructed; one will be connected to an existing branch of the linac based beam, and the other will stand alone. The planned layout is schematically shown in Figure 3 (It also includes an ACAR machine which is not going to be completed soon).

The station to be connected is for the reflection high energy positron diffraction (RHEPD). The RHEPD is a positron version of the reflection high energy electron diffraction (RHEED), but has a quite different characteristic. RHEPD was brought into practical use by Kawasuso [16]. The major difference comes from the positivity of the crystal potential for the positron. Since the crystal potential of materials for the electrons is negative, the electrons incident on a surface at a small glancing angle will be sucked into the materials. It means that the actual incident angle on the crystal lattice plane inside is greater than the initial incident angle on the surface. This causes the electrons to interact with the deeper region under the surface. Also it is impossible to observe a diffraction of the lowest indices. On the contrary, positrons feel positive crystal potential such that they cannot go into the material if incident with a small glancing angle (total reflection) [17]. Thus it is very sensitive to the topmost layer of atoms of the surface and it is possible to observe the lowest index diffraction spots. Fukaya et al. have published several results with their RI-based slow positron beam [18]. If RHEPD works with the linac based intense slow positron beam, fruitful results are expected.

Figure 2. Schematic diagram of the new converter/moderator assembly.
The $^{22}$Na-based slow positron beam is to be moved from RIKEN in Wako. It has been used, for example, to detect the positron-impact X-ray emission cross sections near threshold by Nagashima et al. [19]. It was observed that Cu-K emission shows good agreement with the theory, but not so much in the case of Ag-L emission. The beam was also used to analyse the ion-beam irradiated polymers by Saito et al.[20]. The slow positron depth profile, the AFM observation and the analysis with the nano-cutting machine SAICAS were combined to investigate poly-lactic acid irradiated by He$^+$ ions at 150 keV. The AFM showed that the surface of the irradiated part of the sample subsided with the amount increasing with the ion dose. The SAICAS showed that the ion irradiation depth also increased with the dose. It is not the case for metals, semiconductors, or ionic crystals, where the depth of the effect of ion irradiation is essentially independent of the dose. The SAICAS data and the positron energy dependence of the annihilation ray S-parameter was combined to obtain the density of the ion irradiated part of the sample. The result showed that the density was reduced to be lower than the half of the original value. This machine will be open for the public use after a new $^{22}$Na source is obtained.

It is expected to serve for the researches where the use of a continuous positron beam is essential, as well as for the users who want to use the slow positrons for the first time.

4. Summary
A brief history of the KEK-IMSS Slow Positron Facility, its present status and the plans for near future have been given. Recent results with the Ps time-of-flight, the transmission positron microscope and the photo-detachment of positronium negative ions are shown. In the near future, reflection high-energy positron diffraction (RHEPD) and a $^{22}$Na-based slow positron beam will be installed.

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