Development of a Vertical Slow Positron Beamline at AIST

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A new slow positron beamline with two measurement ports has been installed at AIST. Positrons are generated using the 70 MeV AIST LINAC and are guided to the measurement ports using a solenoid magnetic field. Both beam ports are arranged vertically with the positron beam incident on the sample from above and samples loaded horizontally. Port No. 1 is designed for positron annihilation lifetime spectroscopy (PALS) and Doppler broadening of annihilation radiation (DBAR) measurements with a ~10 mm diameter positron beam. The beamline on port No. 2 contains a transmission type remoderator for a brightness enhanced positron microbeam, similar to the existing positron probe microanalyzer (PPMA) at AIST.

1. Introduction

Positron annihilation lifetime spectroscopy (PALS) and Doppler broadening of annihilation radiation (DBAR) are powerful techniques to study the defect characteristics of materials [1–3]. Using a low-energy (0–30 keV), monoenergetic beam it is possible to control the positron penetration depth from the sample surface to a depth of several microns and is thus used for the characterization of thin films, membranes etc. Production of intense, low-energy (slow) positrons is complicated by the moderation process, in which energetic positrons are implanted into, then subsequently re-emitted from a material with a negative work function for positron emission. This process has a very low efficiency, typically around 10⁻⁴ for commonly used tungsten. Intense positrons beams can be generated using electron accelerators and nuclear reactors [4–7]. At AIST, a 70 MeV linear electron accelerator (LINAC) has been used to produce an intense positron beam for more than 20 years [8,9]. In recent years a positron microbeam apparatus, the positron probe microanalyzer (PPMA), has been developed [10]. Using the PPMA we have extended the functionality of the PALS method to 2D and 3D mapping of defect distributions [11] and to “in air” evaluation via the extraction of focused positron beams through extremely thin vacuum windows [12]. In order to extend the availability of these new measurement techniques to outside users, and to accelerate the development of new measurement techniques we are endeavoring to increase the slow positron beam intensity through the installation of the next generation facility [13, 14]. This facility will be based on a dedicated superconducting accelerator and a newly installed positron beamline. Although the accelerator is still in development, the new beamline is now complete and positrons are currently generated with the existing 70 MeV LINAC. In this contribution we describe the new slow positron beamline.

2. The Slow Positron Beamline

The accelerator based slow positron beam facilities at AIST are shown in Fig. 1. This contribution describes the development of a new positron beamline with the final sections orientated in the vertical direction. The electron beam from a 70 MeV electron LINAC was directed to a newly installed
Existing Positron Beamline (horizontal configuration)

70 MeV LINAC

Superconducting Accelerator (under development)

New Positron Beamline (vertical configuration)

Converter and Moderator

Fig. 1. The electron accelerator based slow positron facilities at AIST. The new beamline has been constructed beside the existing beamline in the same laboratory space. At present positrons are produced by the 70 MeV LINAC, however, in the future it is planned that the beamline will operate with the dedicated superconducting accelerator which is currently under development.

Converter and Moderator

Vacuum

Air

Tantalum Converter, 5 mm

Annealed Tungsten Moderator (~10 V)

Magnetic Coils

Grid (0V)

10 eV, ~10^6/s

Fig. 2. A schematic diagram of the converter and moderator assembly. Electrons are extracted into air and are incident on a 5-mm-thick tantalum disk. Positrons pass into the beamline vacuum chamber and are moderated by the tungsten moderator. By biasing the moderator with respect to an extraction grid the slow positrons are formed into a beam and guided by the solenoid magnetic field.
positron production target. The electron beam is extracted into air through a thin Ti window and is incident on a water cooled 5-mm-thick Ta disk, the converter. The moderator assembly is located directly behind the converter, inside the vacuum, and is composed of a series of thin strips of tungsten films (50 µm) arranged in a grid. The distance between adjacent strips is 5 mm and the total size of the assembly is a circle of diameter 30 mm. The moderator was assembled and then annealed at more than 2000 °C via irradiation with an intense electron beam in a separate vacuum chamber [15]. After annealing, the moderator assembly was installed into the positron beamline as shown in Fig. 2. Positrons are produced in the converter by irradiation of electrons from the 70 MeV LINAC, which typically provides an electron beam with a pulse width of 1 µs–3 µs, a pulse rate of up to 85 Hz and an estimated maximum average electron current on the converter of around 0.5 µA.

![Diagram](image)

**Fig. 3.** The new positron beamline in a) plan view and b) cross section. All dimensions are in mm. Positrons are produced on the left hand side inside the accelerator room. They are transported through the concrete shielding wall and into the experimental room. There are two separate vertical beamlines, port No. 1 is for conventional positron lifetime (PALS) and Doppler broadening (DBAR) measurements and port No. 2 is a positron probe microanalyzer (PPMA).

A cross section of the beamline is shown in Fig. 3. Positrons are extracted from the moderator by applying a bias voltage (typically 10 V), this bias voltage therefore determines the beam energy. The slow positron beam is guided using a solenoid magnetic field of around 80 mT, with all solenoid power supplies fully computer controlled. Positrons are produced in the accelerator room and are transported through the 4-m-thick shielding wall which separates the accelerator room from the mea-
measurement room. This straight 4-m section also contains a linear trap section [9]. In this section, after each positron pulse passes the input gate, a bias is applied closing the trap. The pulse then travels back and forth inside the 4-m linear trap and is released gradually by applying a slowly varying voltage to the output trap electrode.

![Diagram of beamlines](image)

**Fig. 4.** Photograph of the new positron beamline. The existing positron beamline can be seen at the bottom left hand side. The new beamline enters the experimental room behind the concrete shielding and the two separate beamports for PALS/DBAR and PPMA can be seen surrounded by the support frame for the access platform.

After the linear storage section the positron beam enters the measurement room (Fig. 4) and is directed upwards to a height of 4.5 m above the floor level. A specially constructed platform allows access to the beam at this level. The positron beam can then be directed into one of two separate,
vertical beamports. Each beamport has a chopper, pre-buncher and RF buncher in order to produce short pulses for PALS measurements [16]. Port No. 1 is of the conventional type with an unfocussed positron beam and a cross sectional diagram of port No. 1 is shown in Fig. 5. The beamline at port No. 2 is designed to produce a focused microbeam with a similar design to the existing positron probe microanalyzer (PPMA) at AIST [10, 11]. On both beamports samples can be loaded into the sample chamber via a load-lock system with up to 5 samples arranged on a single sample holder. The sample holder can be manipulated remotely to provide automatic measurement. The sample chamber can be biased up to a voltage of $-30 \text{ kV}$, providing an incident beam energy of $(0–30 \text{ keV})$.

Both beamports are arranged vertically, with the positron beam incident on the sample directly from above and samples are loaded horizontally, in contrast to the existing beamline which is horizon-

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**Fig. 5.** Cross sectional diagram of the port No. 1 (PALS/DBAR) showing the bunching system and sample chamber. Dimensions in mm. For PALS measurements long ($\sim \text{ms}$) positron pulses from the linear storage section are first chopped, then bunched by the sub-harmonic pre-buncher and RF buncher so that the pulse width at the sample is around 200 ps.
tal. The vertical arrangement provides several advantages including reduced footprint and alignment accuracy. However, the major advantage is that liquid and powder samples, which are practically impossible in a horizontal arrangement, can now be easily mounted.

To date, we have successfully guided positrons to the sample chamber at port No. 1 and begun DBAR measurements with liquid samples. For these preliminary experiments, liquid was poured into a stainless steel cup shaped container with an inner diameter of 30 mm which is placed directly in the center of the sample chamber. Results of variable energy PALS and DBAR measurements of liquid samples will be reported in a future publication. Positron lifetime spectroscopy at port No. 1 and the operation of the PPMA on port No. 2 are currently under development.

3. Conclusion

A new positron beamline has been developed at AIST. The beamline has two vertically orientated beamports, one for standard lifetime (PALS) and Doppler broadening (DBAR) measurements and a second for microbeam based lifetime measurements (PPMA). Presently, positrons are generated using the AIST 70 MeV electron LINAC. In the future it planned that the new beamline will operate with a dedicated superconducting accelerator currently under development.

A moderator composed of a grid tungsten strips was annealed at > 2000 °C before insertion into the beamline. A fully computer controlled solenoid magnet field guides positrons to the measurement chamber. As samples can be loaded horizontally we have started preliminary DBAR studies on liquid samples which cannot be measured at the existing beamline.

References