Development of a dedicated superconducting accelerator for positron production

B E O’Rourke¹, N Oshima¹, R Kuroda¹, R Suzuki¹, T Ohdaira¹, A Kinomura¹, N Hayashizaki², E Minehara³, H Yamachi⁴, Y Fukamizu⁴, M Shikibu⁴, T Kawamoto⁴ and Y Minehara⁴

¹ National Institute of Advanced Industrial Science and Technology (AIST), AIST-Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305 8568, Japan
² Tokyo Institute of Technology, Research Laboratory for Nuclear Reactors, 2-12-1, Ookayama Meguro-ku, Tokyo 152-8550, Japan
³ The Wakasa Wan Energy Research Centre, 64-52-1 Nagatani, Tsuruga, Fukui 941-0821, Japan
⁴ TIME Corporation, 73-48 Numata Nishi-machi Ohara, Mihara, Hiroshima 729-0473, Japan
E-mail: brian-orourke@aist.go.jp

Abstract. We report on the current status of a project to develop a dedicated superconducting accelerator for slow positron production at AIST. Two 500 MHz, 5 cell cavities will form the basis of the new accelerator. Initial set-up and preliminary design activities are reported.

1. Introduction
The advanced defect characterization research group at AIST is currently generating positrons with a LINAC accelerator and has been at the forefront of variable energy positron based materials characterization using techniques such as positron annihilation lifetime spectroscopy (PALS) [1]. Recently a positron based microbeam analysis system has been developed which has dramatically increased the spatial resolution of PALS measurements [2]. However, this increased resolution comes at a cost of increased time required to analyze a sample as the microbeam needs to be scanned across the sample. The efficiency of such experiments is strongly influenced by the positron intensity at the target. Our group is now planning to install a new superconducting accelerator which will be dedicated to positron production. In this contribution we report on the proposed advantages of the superconducting accelerator and the current progress of the project.

2. Current Accelerator and Positron Beamline at AIST
At present positrons are produced at AIST via a normal-conducting LINAC. The current facilities at the AIST LINAC are shown in figure 1. Electrons from the LINAC at an energy of 70 MeV are directed on to a water cooled tantalum converter and tungsten moderator which produces a beam of slow positrons.

As positrons are only produced when the electron beam is on target, initially the positron beam has the same pulse structure as the accelerator. Typically the LINAC operates with 1 µs pulses at a repetition rate of 100 pps (pulses per second). In order to avoid saturation of detectors during experiments these pulses are stretched in a linear storage section. For PALS
and positron auger electron spectroscopy (PAES) measurements these stretched pulses must then be chopped at high frequency and the short pulses bunched as described in reference [3]. It is clear that this low pulse rate from the LINAC is not suited to such experiments. A higher pulse rate would eliminate the need for such manipulation of the slow positron beam and would substantially increase its transport efficiency.

3. Superconducting Accelerator

In order to improve the situation outlined above it was decided to develop a dedicated accelerator for positron production. This proposed accelerator should be optimized for high current/high pulse rate operation and for this reason it was decided to use superconducting cavities. Our group at AIST has obtained two superconducting accelerator cavities (SCA), originally manufactured by Siemens in Germany and successfully operated since the early 1990’s at the JAERI free electron laser facility [4]. The 5 cell niobium cavities operate at a frequency of 500 MHz and have a total length of 1.5 m. The maximum accelerating gradient is approximately 5 MV/m in pulsed mode and 3 MV/m for continuous operation. In pulsed mode (duty cycle around 3%) one module can therefore accelerate up to 7.5 MeV. For positron production the efficiency is reduced at low energy and an electron energy of more than 10 MeV is required. An initial single pass set-up with both cavities in series should provide a sufficiently high energy to demonstrate positron production but for higher efficiency we envisage adding a re-circulating beamline to enable multi-pass, i.e. high-energy, operation.

A diagram of one of the 5 cell cavity modules is shown in figure 2 (both modules are identical). The modules are composed of a central superconducting chamber manufactured from high purity
Figure 2. 5-cell superconducting accelerator module. Dimensions in mm.

niobium. This chamber is surrounded by a liquid helium tank with a capacity of approximately 400 l. The liquid He tank is further surrounded by two shield layers which are cooled by a separate cryostat and operate at 40 K and 80 K respectively. Finally these shield layers are thermally isolated from the external vessel by an outer vacuum layer.

4. Cavity Commissioning
Since the cavities are not new but were operated successfully at JAERI for more than 15 years it is necessary to test the cavity performance. We have performed several tests on one of the modules in order to confirm its current condition. These tests can be divided into two categories; i) vacuum and ii) refrigeration.

4.1. Vacuum Tests
The integrity of both the internal cavity vacuum and the external isolation vacuum were confirmed. In the case of the internal cavity great care must be taken to avoid introducing contamination onto the cavity walls which can affect the superconducting characteristics, leading to local heating and reduced performance. To this end we performed this test pumping under clean room conditions and ensured that when backfilling with N\(_2\) contaminants were removed from the gas stream before entering the cavity.
4.2. Refrigeration Tests

In order to confirm the operation of the cryostat and heat exchangers a test cooling of the cavity with liquid He was performed. By measuring the temperature at various locations inside the module using internal platinum resistance temperature detectors the operation of both cryostats was monitored and after preliminary cooling with liquid N$_2$ it was possible to introduce liquid He. Efficient collection of liquid He confirmed that both the 4 K and shield refrigeration systems were working properly.

5. Current Status

After testing the operational capacity of one of the modules as described above this module was brought to AIST and lowered into the basement LINAC accelerator hall. It is planned to test and introduce the second cavity later this year. Figure 3 shows a proposed layout for the new beamline including both modules. The proposed beamline runs beside the current LINAC and can be constructed without affecting its operation. At present we are proceeding with simulations of the full accelerator and positron beamline.

6. Conclusion

The advanced defect characterization group at AIST is currently developing a new accelerator dedicated to positron production. Two superconducting cavities have already been obtained and are under test. We have confirmed the vacuum and thermal integrity of one of the cavities and installed it in the AIST LINAC hall. A full beamline design is currently underway and we hope to complete the project within the next several years.

References

[1] Oshima N, Suzuki R, Ohdaira T, Kinomura A, Narumi T, Uedono A and Fujinami M 2009 Rad. Phys. Chem. 78 1096
[2] Oshima N, Suzuki R, Ohdaira T, Kinomura A, Narumi T, Uedono A and Fujinami M 2009 App. Phys. Lett. 94 094196
[3] Suzuki R, Kobayashi Y, Mikado T, Ohgaki H, Chiwaki M, Yamazaki T and Tomimasu T 1991 Jpn. J. App. Phys. 30 L532
[4] Kikuzawa N, Minehara E, Sawamura M, Nagai N, Takao M, Sugimoto M, Ohkubo M, Sasabe J, Suzuki Y and Kawarasaki Y 1993 Nucl. Instrum. Meth. A 331 276