Transactions of the Materials Research Society of Japan 33[2] 267-269 (2008)

Positron Beams generated by an Electron LINAC and their application to Nano-Structures at SPF-KEK

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Positron spectroscopy based on an electron linac brings a new aspect of methodology for positron research. The intensity of positron beam from linac will be little tenth magnitude compared with that of the standard radioisotope based positron source. Generation of Slow positron based on a dedicated linac is described. The application to nano-structures is also presented.

Key words: positron, facility, LINAC, Ps-TOF, microscope

INTRODUCTION

There has been increasing interest in the use of positron beams as "probe" for nano-structure materials in various fields of science. The radio-isotope-based positron source has its several decades history. However, because of its low intensity a radioactive-isotope-based positron beam is not so versatile as a laboratory-based electron beam. A positron spectroscopy based on an electron linac brings a new aspect of methodology for positron and positron application research.

After our new slow positron facility was opened to users in October 2003 under the Joint Development Research scheme at the High Energy Accelerator research Organization (KEK), new results using a positronium-time-of-flight spectrometer (Ps-TOF) have been reported. A new program aiming for the development of a Positron Transmission Microscope was approved by Japan Science and Technology Agency (JST).

The application of positron beams to nano-structures is presented.

SLOW POSITRON FACILITY[1,2]

During FY2006 the Slow Positron Beam line had a total operation time of 1,989 hours, including 1,569 hours of user beam time. The number of effective proposals in FY2006 was 5. One of these proposals is from overseas, and is carried out in cooperation with Japanese researchers as an international collaboration. The users and staff collaborate to promote research in the fields of materials surface science studies, Bose-Einstein condensation (BEC) effects, semiconductor industry related materials studies, positron radiography, and positron imaging.

The facility (Fig.1) consists of a dedicated 50 MeV electron linac, an assembly of slow positron generator, a slow positron transport line and an experimental station for positronium time-of-flight (Ps-TOF) spectroscopy. Transmission Positron Microscope beam line is in the phase of research and development.

At the downstream end of the slow-positron beam-line, a Ps-TOF spectrometer[3] is installed.

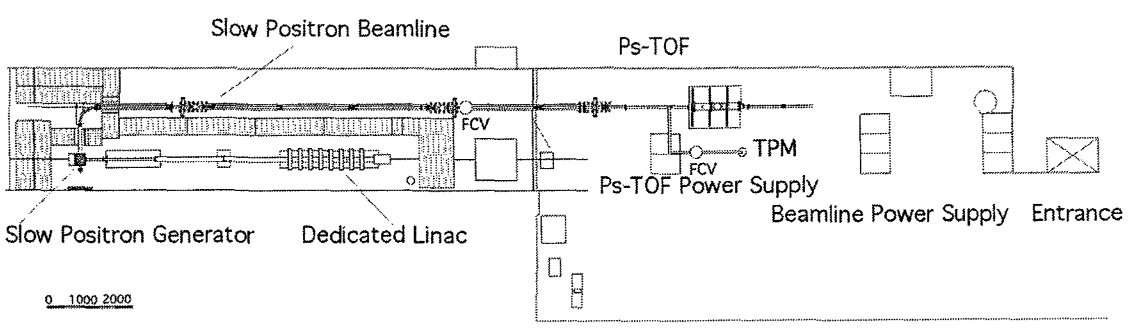

Fig. 1. The Slow Positron Facility. The facility consists of a dedicated 50 MeV linac, the Slow Positron Generator, the Slow Positron transport line and the Ps-TOF spectrometer.

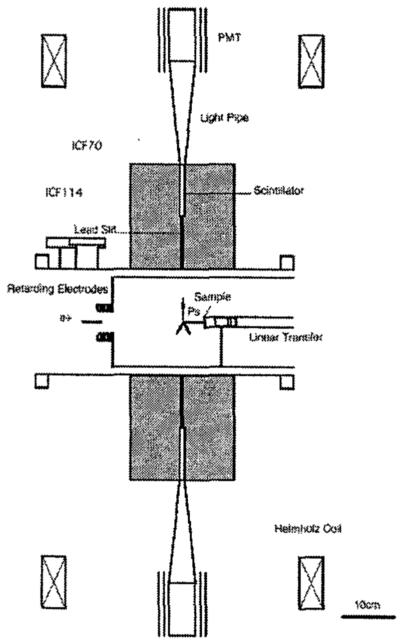

Fig.2. Layout of the Ps-TOF spectrometer.

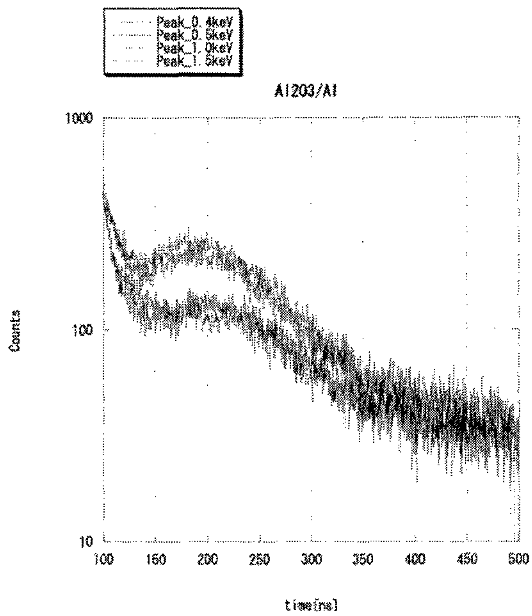

Fig. 3. Obtained Ps-TOF spector of Al_2O_3/Al with different implantation energy of positrons.

The Ps-TOF spectrometer consisted of a sample chamber with a movable sample holder and a set of a plastic scintillator coupled with a photomultiplier tube situated behind a lead collimator with an opening of 4.5 mm. Figure 2 shows the scheme of Ps-TOF spectroscopy. The bunched positrons of 22 ns pulse width were guided by the Helmholtz coil with 60 Gauss from left side and implanted into the sample. Implanted positron and an electron from the sample form positronium. Some of the positronium, emitted from the sample was detected by the photon detector. The pulse heights of annihilation γ rays of ortho-Ps and the time that annihilation event occurs were recorded by a digital oscilloscope (LeCroy Wavepro 960). The digitized waveform data of the detected γ rays were processed on a personal computer.[4,5]

APPLICATION TO NANO-STRUCTURES

As an example results at the Ps-TOF spectrometer, we briefly describe energy-distribution measurements of the Ps emitted from an aluminum oxide thin layer. The surface of the pure aluminum was oxidized with anodizing method. Positron beams are implanted onto this sample.

Figure 3 shows the positron implantation energy dependence of the Ps-TOF spectrum for various positron impact energies, ranging from 0.4 keV to 1.5 keV.

The positronium peak is recorded at around 200 ns. Center of the peak slightly shift to later when the positron beam energy increase. It can be assumed that the initial energy of ortho-Ps may not be lost so much during the escape out process to the surface of the oxide layer. The interaction between oxide layer wall and Ps dependence. This sample is unique compared with other result. Further more experiment will be necessary.

BEAMLINE FOR TPM

We give the advantages of transmission positron microscopes over transmission electron microscopes as follows[5]:

(1) Positrons are repelled by positive ions and inner shells of atoms so that the scattering of positrons is weaker than that of electrons. Positrons are pulled into interstitial sites due to the Coulomb interaction. Use of positrons allows thicker specimens to be used for observing positron images than that with measurements using electrons. Damage of specimens is reduced by using positrons.

(2) The image contrast with transmission positron microscopes may be sharper than that with transmission electron microscopes in some cases. Organic compounds or biomaterials are suitable targets for observation with transmission positron microscopes. These materials are often decorated by metallic ions for increasing contrast. They contain open volumes trapping positrons.

The slow-positron branch line for the transmission positron microscope goes up to near the ceiling of the basement. A working stage 5m above the floor of the basement has been constructed in March 2005. The slow positron guideline will be maintained on this stage. Figure 4 shows the slow-positron branch line for the transmission positron microscope and relevant experimental apparatus. The positron transport line has been constructed to be horizontally, then to turn vertically, and to directly go down to the transmission positron microscope. An old Japan Electron Optics Laboratory (JEOL) transmission electron microscope (JEM100SX), formerly set at the south end of the experimental hall, has recently been moved to the position neighboring the Ps-TOF. JST program has

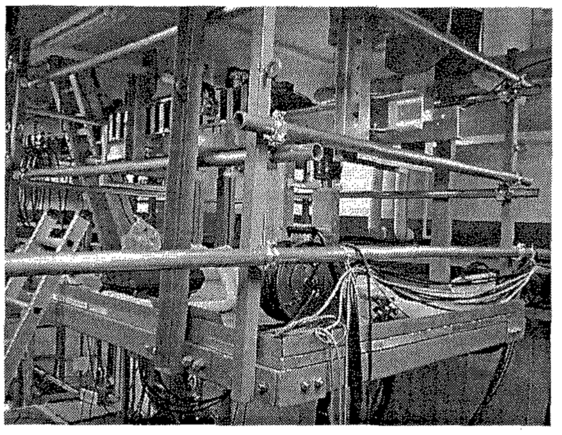

Fig. 4. The slow-positron branch line for the transmission positron microscope

started from September 2005. Newly designed microscope has installed to the experimental hall in the terminal position of the slow-positron branch line for the transmission positron in March 2006.

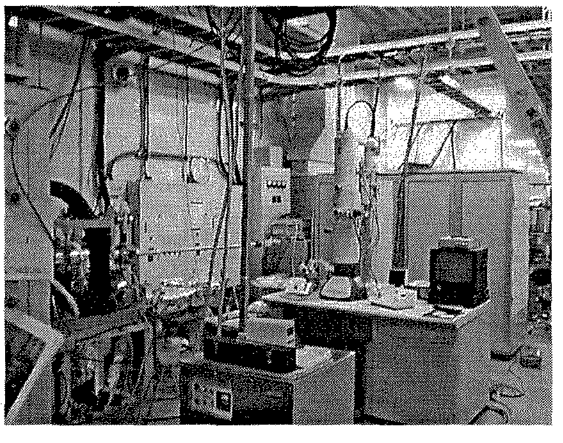

Fig. 5. Newly designed microscope has installed to the experimental hall in the terminal position of the slow-positron branch line for the transmission positron. Left side, Ps-TOF spectrometer is shown.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Prof. O. Shimomura, the Director of Institute of Materials Structure Science, for his encouragement and support. The staff of the KEK electron linac is also gratefully acknowledged for machine operation and support.

They thank Mr. M. Matsuya, and his JEOL group.

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(Recieved September 8, 2007 ; Accepted November 10, 2007)