4 Slow Positron Facility

4-1 Research and Development of Transmission Positron Microscope

Introduction

After the 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 and a JST program aiming for the development of a Positron Transmission Microscope has begun. During FY2006 the slow positron beam line had a total operation time of 1,989 hours, including 1,569 hours of user time. The number of effective proposals including S-type 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.

Research Projects

There were five user groups at the facility in FY2006. The users and staff collaborate to promote research in the fields of Bose-Einstein condensation (BEC) effects, semiconductor industry related materials studies, positron radiography, and positron imaging.

Since September 2005 we have been carrying out the "Transmission Positron Microscope Project" of the Japan Science and Technology Agency (JST). This project is financially supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and the project director is Associate Professor Masanori Fujinami, at the Faculty of Engineering of Chiba University.

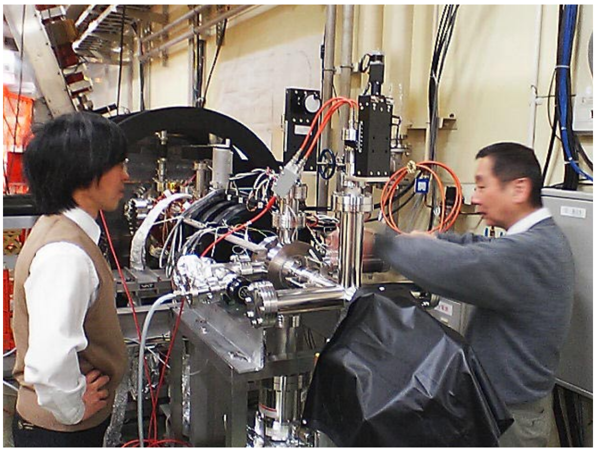

Figure 1
View of the TPM test bench installed at downstream of the Ps-TOF spectrometer.

Preliminary experiments have been made at the Ps-TOF beamline, in collaboration with a group from the Japan Electron Optics Laboratory (JEOL) Ltd. A test bench for the transmission positron microscope (TPM) was installed downstream of the Ps-TOF spectrometer (Figures 1 and 2), consisting of a condenser lens, objective lens, deflector and collimator. A single helmholtz coil was used to generate an inverse magnetic field to form a parallel beam. This parallel beam was focused at the sample by a magnetic lens (CL). The positron beam is monitored using microchannel plate detectors, with retractable positron beam monitors installed at the sample position (MCP1) and at the screen (MCP2).

The positron beam has been successfully focused on the standard sample and its projection image detected on the screen using the microchannel plate detector. The knowledge and experience gained from this test experiment will be applied to the design of the actual TPM.

The TPM branch line was constructed during the

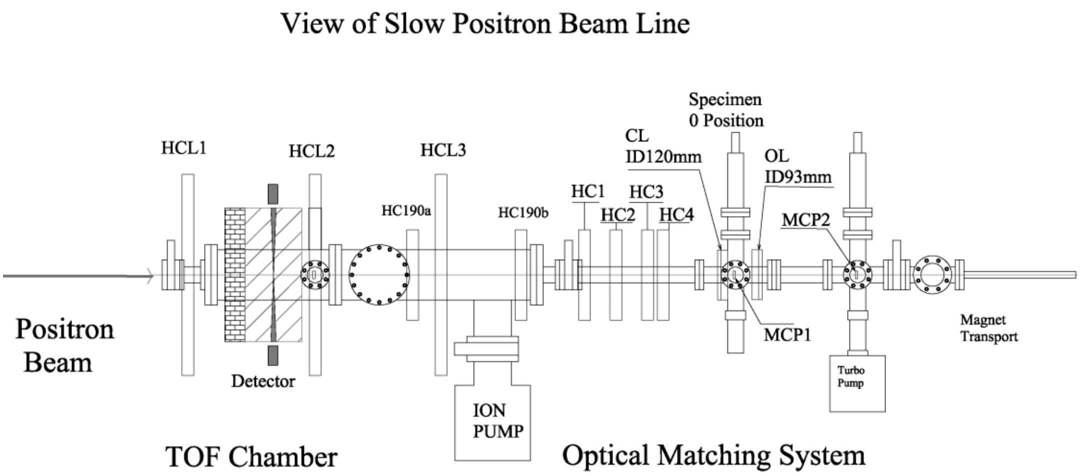

Figure 2
Layout of the Ps-TOF chamber and TPM test bench.

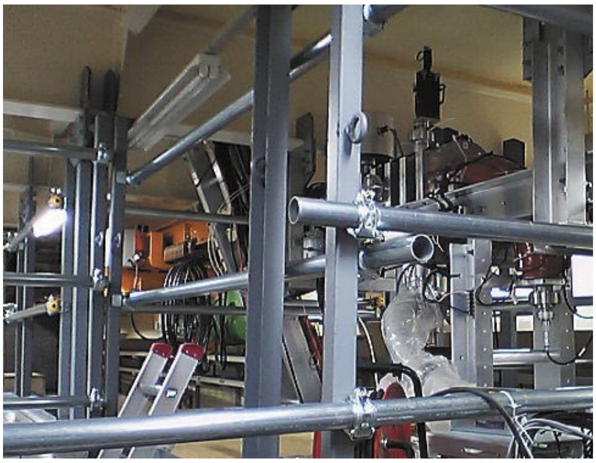

Figure 3
TPM branch line (upper deck). According to the design of the transmission microscope, the source should be at the top, necessitating the branch line to be mounted near the ceiling level.

summer shutdown period of 2006 [1]. The JEOL group, part of the positron team of the JST project, have proposed a feasible design for the TPM. According to their design, the source of the transmission microscope should be at the top of the lens-barrel. The main part of the TPM branch line was constructed on the upper deck near the ceiling of the experimental hall (Fig. 3). Not only standard transportation devices but also a fast-closing-valve system was installed. Sensors for this system will be installed in the boundary section of the beamline end and in the TPM. Beam transport tests were performed from October 2006, successfully transferring the positron beam to the terminal position of the TPM line. The transport efficiency of the positron beam was measured to be 93%. The reduction of neutrons from the Slow Positron Generator enabled us to determine the relative transmission efficiencies of positron beams to the terminal.

References

[1] *Photon Factory Activity Report,* **23A** (2005) 95.

4-2 Scientific Achievements at the Slow Positron Facility

Positronium Time-of-Flight Characterization of Two-Dimensionally Connected Cage-Like Mesoporous Silica

The integration of copper with low-dielectric (low-k) interlayer insulators is required to overcome resistance-capacitance (RC) time delays and crosstalk noise problems in integrated circuits for future generations of computer microprocessors [1]. However, copper is known to have high diffusivities into most promising Interlayer Low Dielectric (ILD) materials, and its presence in the pores of low-k materials results in serious device

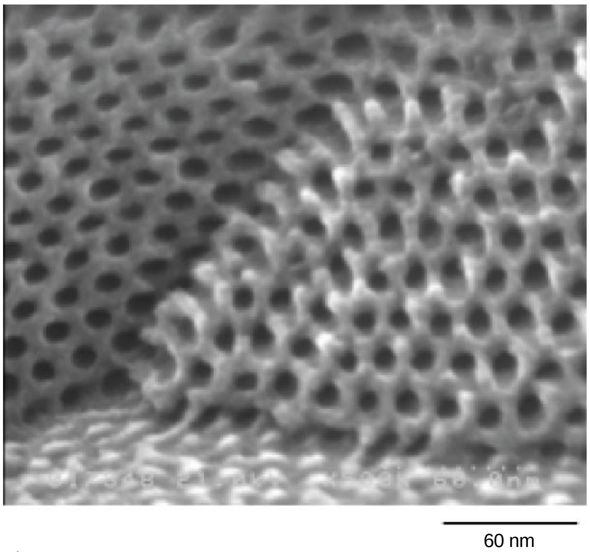

Figure 4
Nano-architectural silica thin film with two-dimensionally connected cage-like pores.

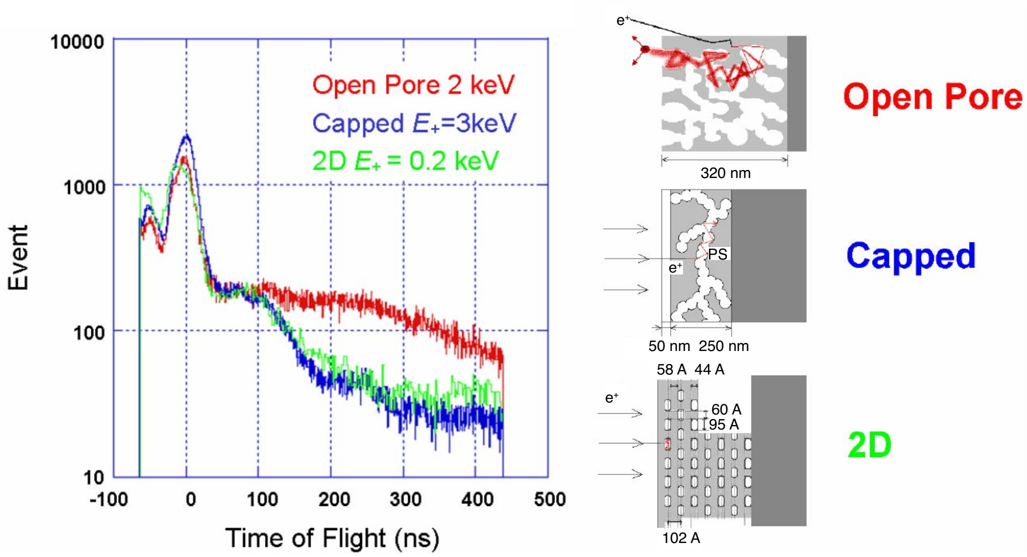

Figure 5
Left: Ps-TOF spectra for open-pored (red), capped (blue), and the present nano architectural silica thin film (green). Right: conceptual view of the three samples: capped, open-pored, and a mesostructured 2-dimensional low-k film. The positron implantation depth for each sample corresponds to 130 nm, 250 nm, and 8 nm, respectively.

degradation and failure. A diffusion barrier is therefore necessary to separate Cu interconnection lines from the surrounding ILD. Since the efficiency of a diffusion barrier is dependent on the porosity of the barrier film, it is important to characterize the barrier on the microscopic scale. Positronium (Ps)-TOF spectroscopy may be the only technique suitable for providing direct information on the porous nature of low-k thin films.

Mesoporous materials form unique structures, for example lamellar, two-dimensional hexagonal, and three-dimensional hexagonal. In some cases, the wall between the pores can be used as an extremely thin diffusion barrier. We recorded Ps-TOF spectra from silica thin-films by changing the slow positron energy. The samples used contain two-dimensionally (2D) connected cage-like pores. As shown in Fig. 4, this type of mesoporous material has an extremely thin pore wall. The results are shown in Fig. 5. By comparing spectra recorded for previously studied capped [2] and open-pored [3] low-k films with the present 2D film [4], it is deduced that more Ps atoms are generated in the open-pore film. As shown in Fig. 5, the spectrum for the present 2D film is different from the one obtained from the open-pored sample, but is very similar to the one from the capped sample, where Ps atoms are produced and confined beneath the capping layer.

In conclusion, the present low-k film has been characterized using the Ps-TOF spectrometer at the Slow Positron Facility. The measurements are consistent with the previous results in which Ps is produced in a capped porous layer, because the self-organized diffusion barrier in the present 2D film has a low porosity, similar to that of the capped film. We have confirmed that the present mesostructure is a possible candidate for the next generation of ILD materials.

References

[1] D. W. Gidley, W. E. Frieze, T. L. Dull, A. F. Yee, E. T. Ryan and M.-M. Ho, *Phys. Rev. B*, **60** (1999) R5157.

[2] H. K. M. Tanaka, T. Kurihara, N. Nishiyama, T. Maruo and A. P. Mills, Jr., *Microporous and Mesoporous Materials*, **95** (2006) 164.

[3] H. K. M. Tanaka, T. Kurihara and A. P. Mills, Jr., *Phys. Rev. B* **72** (2005) 193408.

[4] H. K. M. Tanaka, T. Kurihara and A.P. Mills, Jr., Positronium, *J. Phys.: Cond. Matt.,* **18** (2006) 8581.