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Construction of a positron microbeam in JAEA

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ABSTRACT

We have developed a positron microbeam using magnetic lenses based on the commercial scanning electron microscope (SEM). A slow positron beam was generated using a handmade source with ^{22}Na and a solid neon moderator. The beam diameter was 3.9 μm on a target. Two-dimensional image of *S* parameter was successfully obtained. By introducing a beam pulsing section, positron lifetime measurement beam is also available.

1. Introduction

Using a positron microbeam, spatial distribution of positron annihilation near subsurface region can be obtained. Positron microbeam is also useful for the study of small objects. For instance, it is possible to investigate the relation between vacancy-type defects and crack progress of nuclear materials, and the degradation analysis of semiconductor devices. Several positron microbeams have already been developed [1–5]. Munich group successfully formed a positron microbeam with a diameter of 2 μm using a remoderation technique and an in-lens type objective lens [1,2]. Bonn group also succeeded to form a positron microbeam with a diameter of 20 μm using a small source and an out-lens type objective lens of the scanning electron microscope (SEM) [3,4]. To obtain such positron microbeam, it is necessary to use objective lenses, which are commonly used in the electron microscopy. We also attempted to form the positron microbeam using a positron beam for the positron diffraction experiment and a SEM optics [6–8]. The initial beam diameter (4 mm) was reduced to 80 μm. However, this spatial resolution is not high enough. To focus beam more, a small positron source should be fabricated. In this work, we developed a positron microbeam by a small source, a solid neon moderator, magnetic lenses and a SEM optics. In addition, a beam pulsing system was also developed which allows the positron annihilation lifetime spectroscopy (PALS) measurement.

2. Construction of positron microbeam

Fig. 1 shows the schematic drawing of the apparatus. The individual parts are described below.

2.1. Slow positron generation system

To focus the beam effectively, the reduction of the initial emittance is required. We developed a sealed source as shown in Fig. 2(a). Sodium-22 of 55 MBq was deposited into the 2-mm diameter hole on a tungsten–copper block and sealed by a capsule with a Ti window of 5 μm thickness. Sodium-22 was sealed perfectly and no leakage was detected. Fig. 2(b) shows the schematic drawing of the positron gun. The source is mounted on the top of a cold head with a radiation shield, and cooled down to 4 K. A solid neon film was grown on the source window as a moderator [9]. Slow positrons were extracted by the immersion lens system composed of an extractor, a wehnelt, a Soa and an anode [6]. The numerical calculation indicated that the beam diameter can be reduced to 0.2 mm at the gun exit when the beam energy is 20 keV.

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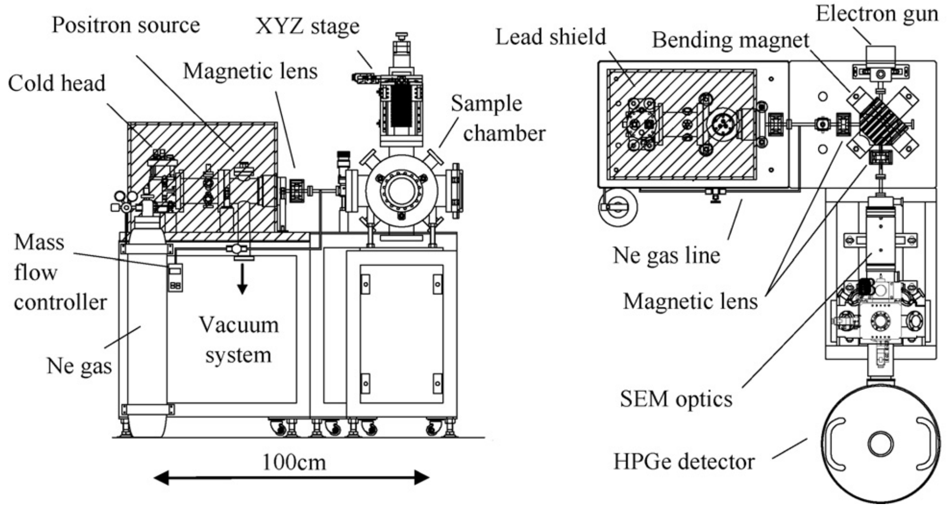

Fig. 1. Schematic drawing of the positron microbeam apparatus. The left picture is side view and the right picture is top view.

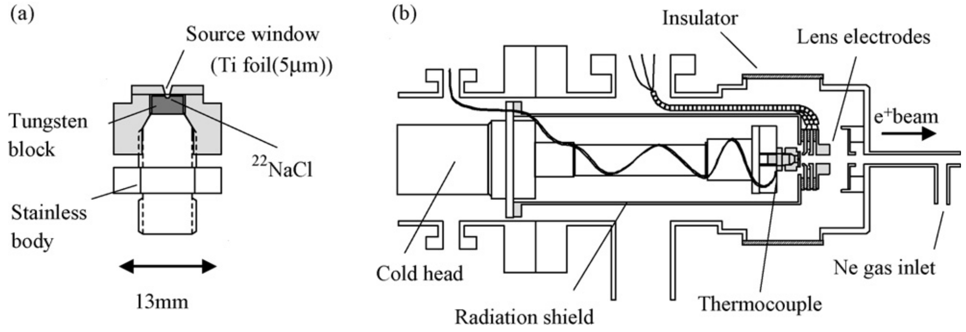

Fig. 2. Schematic drawings of (a) the positron source capsule and (b) the positron gun. The source is installed on the top of the cold head and cooled down to 4 K.

2.2. Transportation system

The slow positron beam was transported by three magnetic lenses. To remove positrons transmitted the moderator without thermalization and gamma rays from the source, the positron beam was bended to an angle of 90° with a magnetic prism. To focus the beam in two directions without distortion, the pole piece was inclined by 3.247°. The positron beam was injected to the SEM optics (Topcon SM-300), which is composed of a projector lens, a middle lens and an objective lens (out-lens type). The work distance of the objective lens was set to 10 mm. An adjustable collimator (0.5 mm diameter) which is considerably large compared to that used for the electron beam focusing can be installed in front of the objective lens.

2.3. Scanning system

By moving the sample stage to the X–Y direction, the beam is scanned in two dimensions. The minimum moving step of the XY stage is 1 μm. The Doppler-broadening of annihilation radiation is measured using a Germanium detector (Canberra 6519) with an efficiency of 65% and an energy resolution of 1.85 keV (@ 1.33 MeV peak of ^{60}Co). The detector is placed behind the specimen to maintain high-counting rate. The beam scanning, the measurement of gamma rays and the calculation of $S(W)$ parameter are fully automated.

2.4. Pulsing system

Positron lifetime measurements can be realized by utilizing a pulsed positron beam. For this purpose, a bunching unit [10,11] is connected to the positron generation system. In this mode, the positron beam with energy of 10 eV generated by the positron gun is transported to the bunching unit in the continus guiding magnetic field. The schematic of this pulsing system is shown in Fig. 3. The DC positron beam is first bunched to several nanoseconds at the pre-buncher with a 50 MHz t^{-2}-wave. To enhance the peak-to-background ratio, the beam in the unbunched phase is removed by the parallel-electrode type chopper, which is driven by a 25 MHz sine wave. Scanning on a 2-mm wide slit by a transverse electric field, positron beam cut off by approximately 2 ns. Finally, the positron beam is further bunched by the resonator-type main buncher driven by the superimposed wave with a 200 MHz sine and its third harmonics. From the numerical

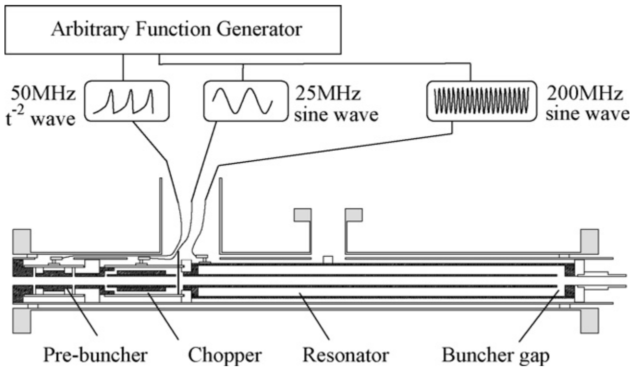

Fig. 3. The schematic drawing of beam pulsing system.

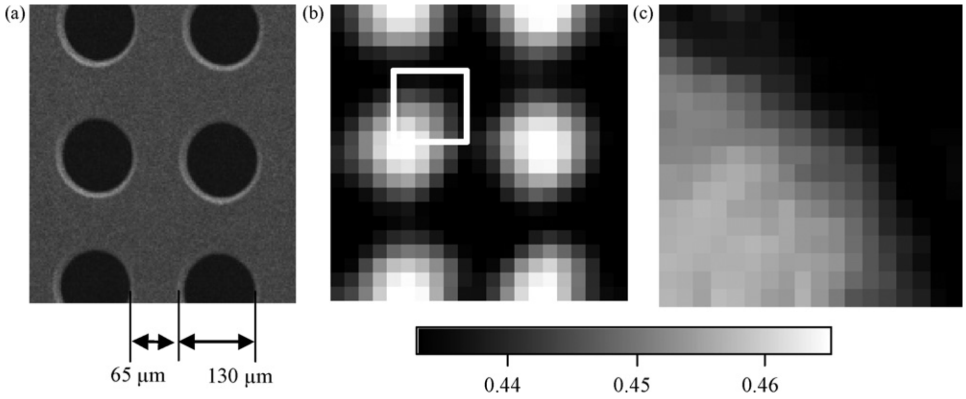

Fig. 4. (a) SEM image of the stainless mesh. (b) The spatial distribution of *S* parameter with the scan area of 400 μm × 400 μm. (c) The spatial distribution of *S* parameter with the scan area of 80 μm × 80 μm which corresponds to the square in (b).

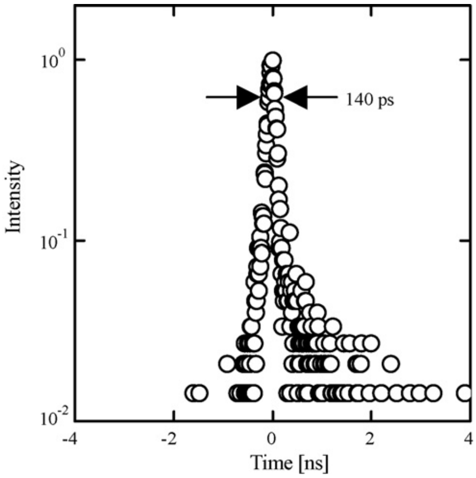

Fig. 5. The time structure of the bunched positron beam measured by the MCP. The peak-to-background ratio is higher than 1000. Time calibration is 10.0 ps/ch.

calculation, the final pulse width (FWHM) was estimated to be 100 ps. The pulsed beam is extracted from the continus magnetic field by accelerating up to several keV, and focused using a magnetic lens. Subsequently, the pulsed beam is injected to the SEM optics. The detail of this section was described elsewhere [8].

3. Performance test

By scanning the beam across a sharp metal knife-edge in front of a silicon wafer, the beam diameter was measured. The minimum diameter was 14.8 μm without the collimator. The counting rate was approximately 150–200 cps. When the collimator was inserted, the beam diameter was reduced to 3.9 μm, though the counting rate reduced to one-fifth. Fig. 4 shows the results of the two-dimensional scan of a stainless steel mesh having evenly distributed holes. Fig. 4(a) is the SEM image of this mesh. The hole diameter is 130 μm and the interval is 65 μm. Resin is poured into each hole for the high contrast of *S* parameter. Fig. 4(b) shows the *S* parameter distribution of this mesh. The scan area was 400 μm × 400 μm and scan step was 20 μm. The arrangement of the holes is the same as the SEM image. Fig. 4(c) shows the zoom image of the part of a hole indicated by the square in Fig. 4(b). The scan area was 80 μm × 80 μm and scan step was 5 μm. The edge of the mesh is appeared clearly. These results show that our positron microbeam is capable to study a small structure, which has the same dimensions as the mesh we used.

In order to confirm the beam pulsing, the positron source was attached to the pulsing unit and beam bunching was performed. The time structure of the bunched positron beam is shown in Fig. 5. The PALS measurement system using a digital oscilloscope (LeCroy wavepro7100A) was used for the measurement of the pulse width. The start signal was obtained from the buncher system. Positrons were detected by a high-speed MCP (Hamamatsu F4655-13). The time resolution of this MCP is approximately 25 ps. The stop signals are the anode outputs. The pulse width was determined to be 140 ps in FWHM. This is sufficient pulse width for the positron lifetime measurement.

4. Conclusion

We developed a new positron microbeam. We succeeded to focus the positron beam to 3.9 μm. We also demonstrated the *S* parameter spatial mappings using a test mesh. The beam pulsing system, which can form a pulsed beam of 140 ps, was also developed

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References

[1] A. David, G. Kögel, P. Sperr, W. Triftshäuser, Phys. Rev. Lett. 87 (2001) 067402.
[2] W. Triftshäuser, G. Kögel, P. Sperr, D.T. Britton, K. Uhlmann, P. Willutzki, Nucl. Inst. Methods B 130 (1997) 264.
[3] U. Männig, K. Bennewitz, H. Bihr, M. Haaks, W. Sigle, C. Zamponi, K. Maier, Appl. Surf. Sci. 149 (1999) 227.
[4] H. Greif, M. Haaks, U. Holzwarth, U. Männig, M. Tongbhoyai, T. Wider, K. Maier, J. Bihr, B. Huber, Appl. Phys. Lett. 71 (1997) 2115.
[5] G.R. Brandes, K.F. Canter, T.N. Horsky, P.H. Lippel, A.P. Mills Jr., Rev. Sci. Inst. 59 (1988) 228.
[6] A. Kawasuso, T. Ishimoto, M. Maekawa, Y. Fukaya, K. Hayashi, A. Ichimiya, Rev. Sci. Inst. 75 (2004) 4585.
[7] R.S. Yu, M. Maekawa, Y. Miwa, T. Hirade, A. Nishimura, A. Kawasuso, Phys. Stat. Sol. (C) 4 (2007) 4016.
[8] M. Maekawa, R.S. Yu, A. Kawasuso, Phys. Stat. Sol. (C) 4 (2007) 3577.
[9] A.P. Mills Jr., E.M. Gullikson, Appl. Phys. Lett. 49 (1986) 1121.
[10] P. Willutzki, J. Störmer, G. Kögel, P. Sperr, D.T. Britton, R. Steindl, W. Triftshäuser, Meas. Sci. Technol. 5 (1994) 548.
[11] R. Suzuki, Y. Kobayashi, T. Mikado, H. Ohgaki, M. Chiwaki, T. Yamazaki, T. Tomimasu, Jpn. J. Appl. Phys. 30 (1991) L532.