phys. stat. sol. (c) **4**, No. 10, 4016–4019 (2007) / **DOI** 10.1002/pssc.200675821

Design of a positron microprobe using magnetic lenses

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Received 23 July 2006, accepted 23 May 2007

PACS 07.78.+s, 41.75.Fr, 41.75.Ht, 41.85.–p, 84.30.Sk

We have designed a positron microbeam using magnetic lenses based on the commercial scanning electron microscope (SEM). Employing a source with a diameter of 1 mm and an immersion lenses, the diameter of primary beam can be reduced to 200 μm. This could be further reduced to less than 10 μm using the SEM optics. By introducing a beam pulsing section, positron lifetime measurement using a pulse beam will be also enabled. The extraction of positron beam from the magnetic field was simulated numerically.

1 Introduction Lateral scanning of a positron microbeam can provide the spatial distribution of positron annihilation near the subsurface region. This technique is useful for the study of small domains, such as cracks, whiskers and voids. Several positron microbeams have been already developed [1–7]. Munich group successfully formed a positron microbeam of diameter of 2 μm using the remoderation technique and an in-lens type objective lens [1–3]. Bon group also successes to form a positron microbeam of diameter of 20 μm using small source and an out-lens type objective lens of the scanning electron microscope (SEM) [4, 5]. To obtain such positron microbeam, a well-focused and monoenergetic positron beam and an objective lens, which is commonly used in the electron microscopy, are required. We have attempted to form the positron microbeam using a high brightness positron beam for the positron diffraction experiment [8, 9]. The beam diameter is ~80 μm and counting rate is ~50 cps, which is not enough for the detail two-dimensional scan of samples. In addition, positron lifetime measurement is hardly carried out because of the DC beam. In this work, we therefore designed a new positron microbeam and carried out the feasibility study.

2 Construction details Figure 1 shows the schematic drawing of positron microbeam that we have designed. The details of each parts are shown below.

2.1 Positron gun To generate a high-brightness positron beam, a sealed source with an active diameter of 1 mm will be used. The cross-sectional schematic view is shown in Fig. 2(a). Sodium-22 will be (~37 MBq) deposited on a tungsten block with a 1 mm-diameter hole. This will be sealed by a capsule with a Ti window of 5 μm thick. This source is mounted on a cold head and cool down to ~4 K. Rare-gas solid (RGS) moderator is formed on the source window by introducing Neon gas. Slow positrons are extracted by an immersion lens system composed of extractor, wehnelt, a Soa and an anode which are developed for positron diffraction before [8]. The beam formation is simulated by the SIMION7 code [10]. The result is shown in Fig. 2(c). Initial beam energy and its dispersion were set to 2 ~ 3 eV. The angle distribution was ±15°. Longitudinal energy spread was 0.5 ~ 0.7 eV. Acceleration voltage was set to 20 keV. At the

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gun exit, a beam diameter of 0.2 mm was obtained. Compared with the present beam (Fig. 2(b)), it decreases about 1/5. Using the SEM optics, this primary beam will be focused down to less than 10 µm.

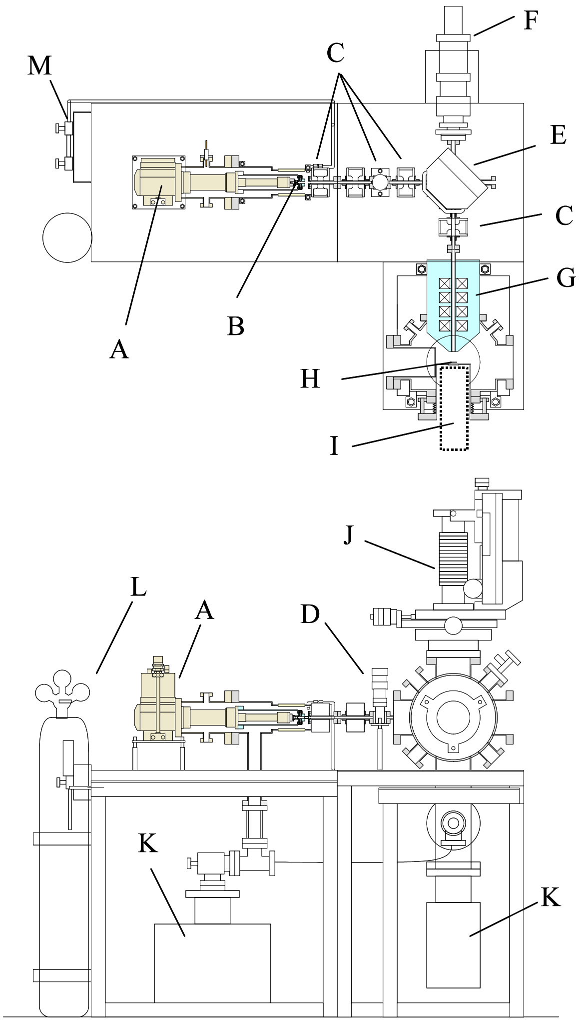


Fig. 1 Schematic of positron microbeam. The bunching unit is not shown. A: cold head, B: positron source, C: magnetic lenses, D: gate valve, E: bending magnet, F: electron gun, G: SEM system, H: sample holder, I: Ge detector, J: XY stage, K: vacuum pumps, L: Neon gas, M: mass flow controler.

2.2 Beam transportation and microbeam formation The positron beam generated by the positron gun is transported by four magnetic lenses. The diameter of the pole piece of these magnetic lenses is 10 mm. Positron beam is bended to an angle of 90° with a magnetic prism. The pole piece of this magnet has a inclination of a 3.247° for *n*-value adjustment [8]. This works for 2-direction focusing to a beam preventing the distortion of the beam shape. Finally, positrons are injected to the SEM system. Electron beam can be also used for the normal SEM mode.

On the test bench equipped with the SEM magnetic lens, we have performed the formation of positron microbeam and evaluate the properties of this beam [9]. It was confirmed that positron beam was converged to ~80 µm when the source diameter was 4 mm. It is expected that the beam diameter of 10 µm will be formed when the small source and high performance objective lenses based on commercial SEM are used.

2.3 Beam pulsing Positron lifetime measurement can be realized by utilizing a pulsed positron beam. For this purpose, a bunching unit is connected to the positron gun. In this case, the positron gun generates a slow positron beam with energy of 10 eV. It is transported by the guiding magnetic field to the bunching unit. This continuous positron beam is bunched by the high frequency electric field using radiofrequency (RF) technique [11, 12]. The diagram of this pulsing system is shown in Fig. 3(a). This bunching unit is composed of the following three parts; (i) a pre-buncher, (ii) a chopper and (iii) a main buncher. The DC positron beam is first bunched at the pre-buncher with 50 MHz saw tooth t^{-2} waveform and converted into a pulsed beam. The pulse width is assumed to be several nanoseconds. Subsequently, to improve the peak-to-background ratio, background components existing among bunched beams are cut by the chopper. A simple 25 MHz sine wave was applied to the parallel electronode as a chopping waveform. Finally, positron beam is bunched to the pulse with the width of 100 ps by the resonator-type main buncher driven by the 200 MHz modified sign wave which is superimposed the 3rd harmonics. Figure 4(b) shows the result of beam pulsing obtained by numerical calculation. From this result, the pulsed beam of width of 100 ps (FWHM) having high peak-to-background ratio will be obtained.

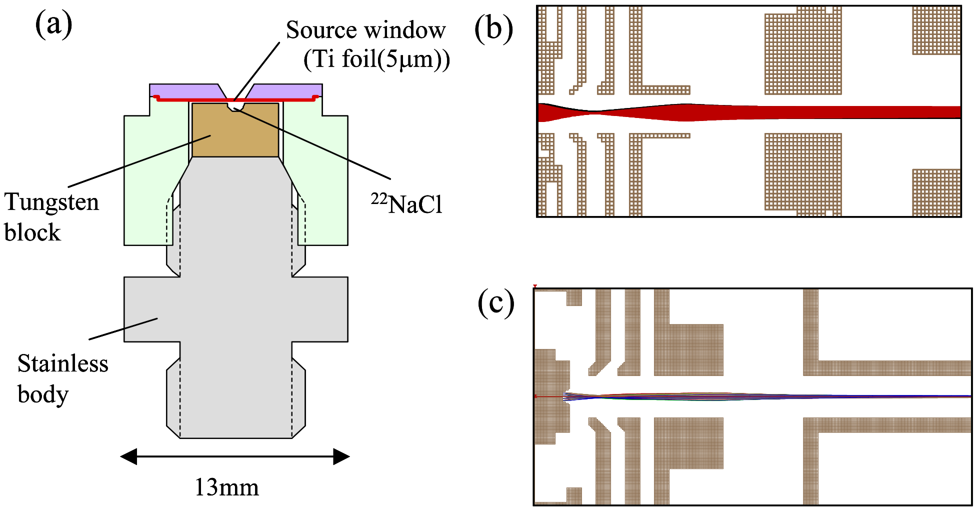
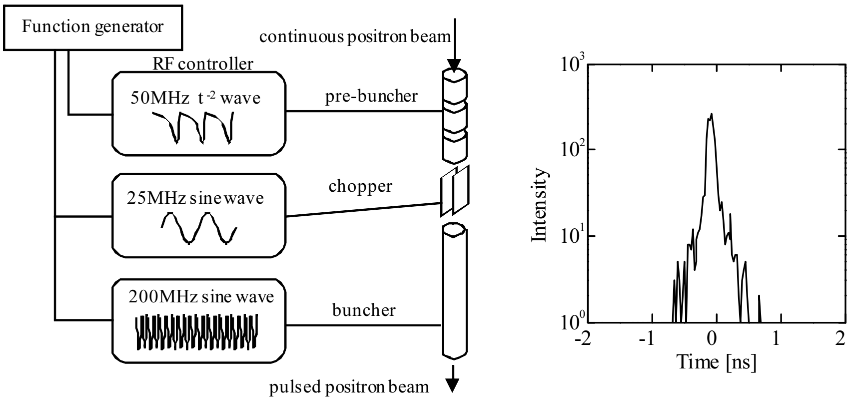


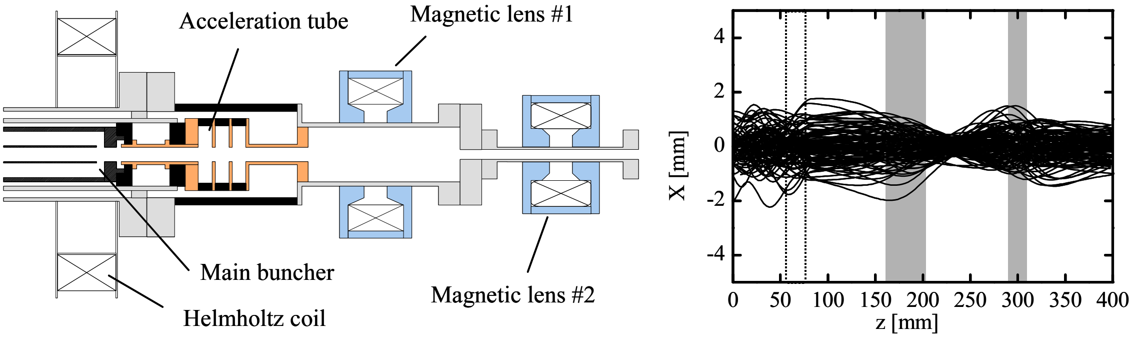
Fig. 2 (a) The new positron source. ^{22}NaCl of 37 MBq is dropped on a tungsten block and sealed by a source window with Ti foil which thickness is 5 μm. The window diameter is 1 mm. Beam simulations were carried out by the SIMION7 code. (b) is the same as the test bench. The beam size at the exit of the gun is 0.85 mm. (c) is new one. The beam size at the exit of the gun is 0.2 mm.



(a) (b)

Fig. 3 (a) The schematics of pulsing unit and (b) the result of numerical calculation of the behavior of pulsed beam. The pulsed beam of 100 ps (FWHM) is obtained.

For the microbeam formation, it is necessary to extract the beam from a guiding magnetic field where the pulsed beam is formed in the guiding magnetic field. For this purpose, an extraction unit is installed after the buncher unit. The schematic drawing is shown in Fig. 4(a). The pulsed positron beam is extracted from the magnetic field by accelerating up to several keV at an acceleration tube. By the magnetic lens #1, the accelerated beam is focused and transported .The magnetic lens #2 is the same lens for beam transportation shown in 3.2. Figure 4(b) shows the numerical simulation of the beam. The dotted lines



(a) (b)

Fig. 4 (a) The schematics of the extraction unit, (b) the result of numerical calculation of the beam behavor at this extraction unit. Positron beams can be extracted without divergence.

denote is the position of the acceleration tube. Dark areas show the position of magnetic lenses. The beam energy is 10 keV. It is confirmed that the beam could be extracted from the guiding magnetic field by the acceleration tube, and also confirmed that the beam is converged by the two magnetic lenses.

3 Conclusion We have designed new positron microbeam. When small source with the 1 mm active diameter is used, formation of the positron microbeam converged on 10 μm is expected. The buncher unit which can form the pulsed beam of 100 ps and the beam extraction unit from the guiding field are also designed.

Acknowledgements Financial support from Japan Science and Technology Agency (JST) under the "Innovative Nuclear Research and Development Program" is acknowledged.

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