DEVELOPMENT OF A SYNCHRONIZATION SYSTEM BETWEEN POSITRON BEAM AND LASER

K. Kanno†, Y. Honda, M. Tashiro, T. Yamaguchi, G. Isoyama, S. Tagawa
The Institute of Scientific and Industrial Research, Osaka University
8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Abstract

The new experiment is planed to understand the behavior of positroniums in materials by direct excitation of positroniums using laser. In this experiment, the high-density bunched positron beam is required. The new facility for this experiment was designed. And it was found that the numerically estimated number of available positrons were about 1.1×10^5 and the pulse width was 200 ps.

1 INTRODUCTION

It is known that energetic positrons injected into a material lose their kinetic energy rapidly by inelastic scattering with atomic electrons dominantly until their energy fall less than the ionization energy. And these decelerated positrons reach to thermal energy, so-called thermalization, by generation of the exciton and the phonon excitation. After thermalization they diffuse and annihilate with electrons. The annihilation rate depends on the electron density in the material. If there are free-volumes in the material, the positrons can be trapped there efficiently and the positron lifetime becomes longer because of lower electron density. In polymer, some positrons can form a bound state with electrons known as positroniums (Ps) which are trapped in the free volume. As the lifetime of the orthopositronium (*o*-Ps), whose spin direction is in parallel, reflects the size of the free volume, the positron annihilation lifetime spectroscopy plays an important role in detecting the free volume of atomic sizes. This is the powerful tool to characterize the free volume. Various interactions concern the factor of the *o*-Ps lifetime definition. Our purpose is to investigate the behavior of the *o*-Ps in materials and its relationship with lifetime. As an excited *o*-Ps is easier to be influenced by the surrounding potential barrier than the *o*-Ps on the ground state, it is possible to obtain the information concerning this potential by the use of direct excitation of the *o*-Ps. By changing the irradiation timing and wavelength of laser on the bunched positron beam systematically, several kinds of interactions take place between the Ps and the materials. In this experiments, the bunched positron beam which consists of 1~10 thousands of positrons are required. However, it is impossible to obtain the high-density positron beam by using present system based on the S-band electron linac at ISIR, Osaka University [1].

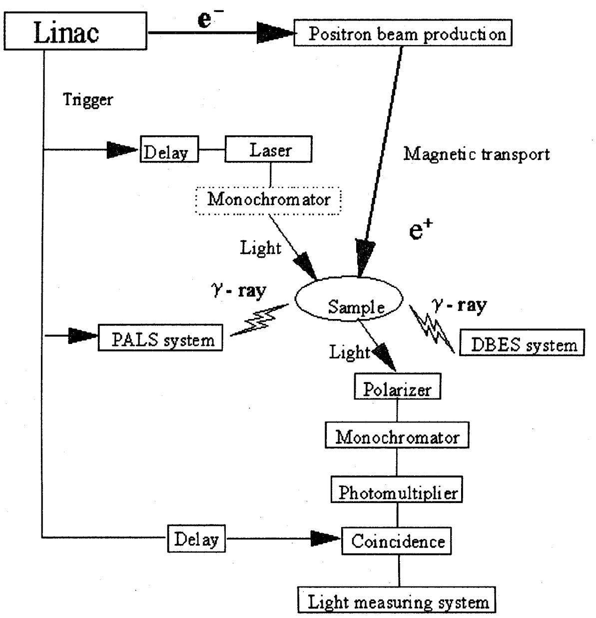


Figure 1: Measuring system based on the L-band linac.

Therefore we decided to use the L-band electron linac at ISIR, which can produce high-density electron single bunch beam.

The number of the Coulomb per pulse of this linac is 91 nC, and pulse width is 20 ps.

The block diagram of measuring system is shown in Fig. 1.

2 THE TRANSPORT SYSTEM FOR THE ELECTRON BEAM PASSING FROM THE BENDING MAGNET TO THE POSITRON GENERATOR

The distance between the bending magnet and wall of the linac room is about 4 m as shown in Fig. 2. A converter that is used to generate the positrons and some quadrupole magnets are placed on this length. The beam size of the electron, which is injected into the converter, is required to be as small as possible.

The L-band linac is operated at 28 MeV and its emittance is about 5π mm·mrad.

†kanno25@sanken.osaka-u.ac.jp

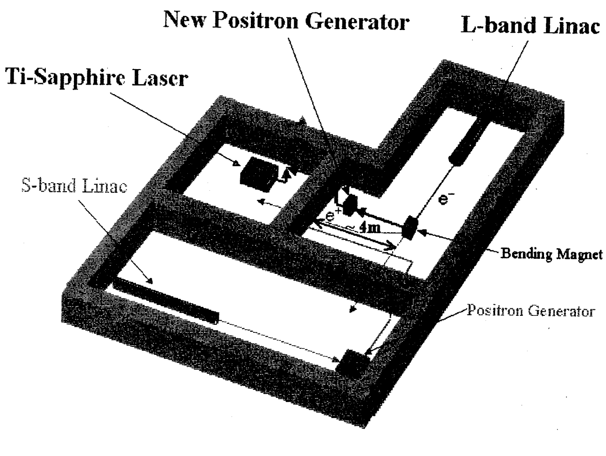


Figure 2: Facility section

The trajectories of electrons were calculated by the use of transfer matrices, and the transport system was optimized in order to minimize the beam size on the converter by using simplex method [2]. When adapting only quadrupole triplet to this system, one of the exciting current values of the coil of quadrupole magent was over its capacity. When adapting quadrupole triplet with singlet to this system, it was found that the combination of the parameters, which were every exciting current of coils of Quadrupole magnet and the position of quadrupole magnets and the converter, existed as the values which were able to realize. Design of the transport system and the motion of the electron beam in the phase space are shown in Fig. 3 and Fig. 4, respectively.

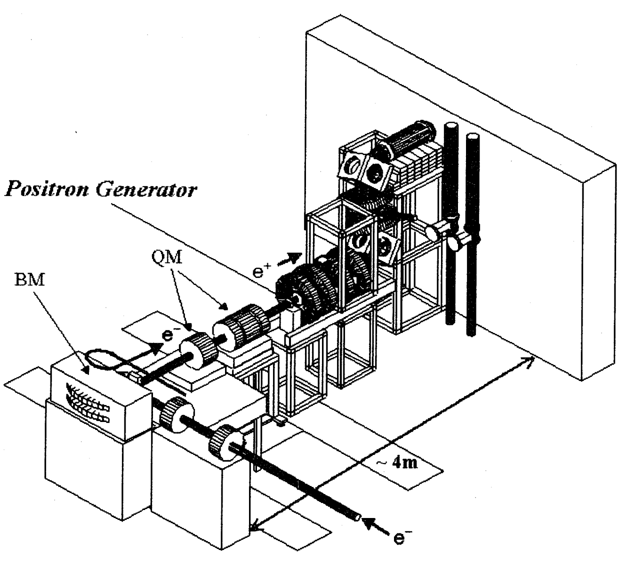
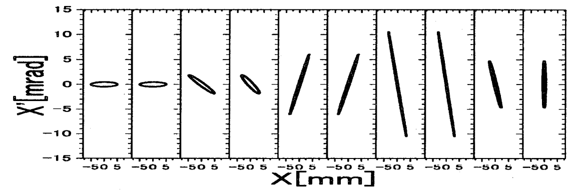
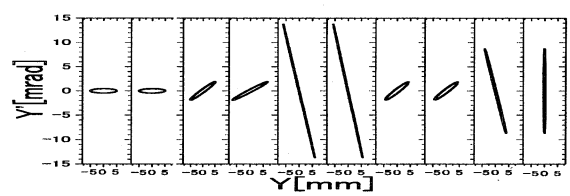


Figure 3: Design of the beam line



The motion of the electron beam in the xx' phase space



The motion of the electron beam in the yy' phase space

Figure 4: The motion of the electron beam in the phase space passing from the BM to the converter. These components are perpendicular to the beam axis. From left to right, each graph shows diagram at exit of the BM, the entrance and the exit of 4 QMs, and on the converter, respectively.

3 DESIGN OF THE POSITRON GENERATOR

We decided to use only the converter as the positron generator, since the moderator causes widening of the pulse width to the bunched positron beam.

EGS4 program [3] was used to estimate the number of positrons produced in the converter. The tungsten disc was selected as the converter. In this program, the cut-off energies for an electron and a positron are limited to 10 keV. Actually, the positrons still go further loosing their energy less than 10 keV by inelastic collisions. However, this distance was no need to be taken into account, since it could be estimated less than 100 nm [4], and this length was small compared with diffusion length. In the region with thickness of 1μm from the end surface of the converter, the number of positrons was estimated by varying thickness of the converter. The dependence of the production efficiencies on the thickness of the converter are shown in Table 1, where these efficiencies are defined as the number of produced positrons in this region divided by the number of the incident electrons

Table 1: Dependence of the production efficiencies on the thickness of the converter

Converter thickness (mm)	Efficiency ($\times 10^{-6}$)
1	0.8 ± 0.3
2	2.4 ± 0.5
3	2.8 ± 0.8
4	2.8 ± 0.6
5	2.8 ± 0.8
6	1.8 ± 0.6

Table 2: Production efficiencies of positrons from electrons when equipped the reflector

(Converter thickness: 4 mm) $\times 10^{-6}$

		Reflector thickness (mm)				
		0.1	1	2	3	4
Gap (mm)	1		4.7±0.9	3.6±1.2		
	2	2.8±1.0	6.4±1.6	4.8±1.4	2.4±1.0	
	3		6.4±1.1	6.0±1.1	7.7±1.6	6.2±1.1
	4		5.2±1.0	4.0±1.4		

It was found that optimum thickness for the converter was 4 mm and conversion rate from an electron to a positron was $(2.8 \pm 0.6) \times 10^{-6}$. Furthermore, the conversion rate when the reflector was equipped was also estimated for the sake of increasing efficiency, and these results are shown in Table 2.

It was found that optimum reflector thickness and gap, between the converter and the reflector, were 3 mm and 3mm, respectively, and then conversion rate was $(7.7 \pm 1.6) \times 10^{-6}$. The design of the positron generator is shown in Fig. 5.

The arriving rate at end surface of positrons staying in this region was also estimated by solving one dimensional diffusion equation, in which several assumptions were adopted such that the diffusion constant for positron was uniform and was 1.5 cm^2/s, lifetime was 150 ps. The results showed that about 4.5 % of positrons included in 1 μm thick region could reach the end surface at maximum and also about 94 % of these positrons could reach surface within 100 ps and about 99 % within 200 ps as shown in Fig. 6. The total conversion rate from an incident electron to positrons arriving at end surface could be deduced from above results to be about 3.5×10^{-7}. When the number of incident electrons is 3×10^{11}, about 1.1×10^{5} positrons are expected to obtain within about 200 ps.

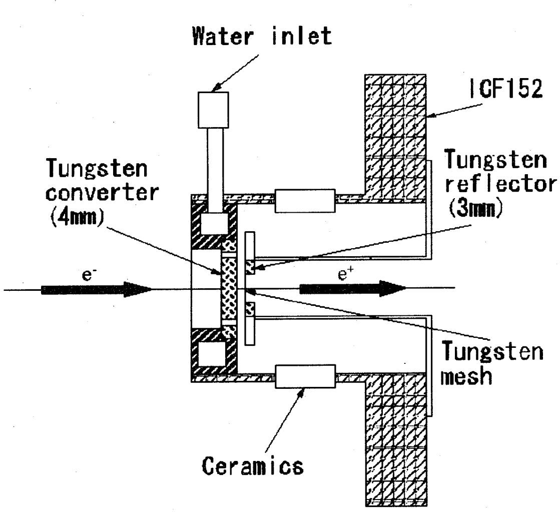


Figure 5: Design of the positron generator

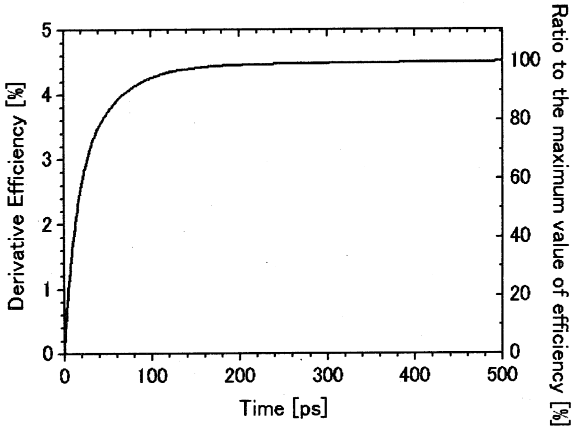


Figure 6: Derivative efficiency corresponding to time

The pulse width will be stretched to some in the transport tube, since each positron travels along the different field line. To suppress this stretching effect, a simple beam line composed of two bending sections was considered and it was found that the smaller diameter and higher transport energy would suppress the stretching in this beam line. When the positron beam is 10mm diameter, the transport energies: 100 eV, 1 keV, 10 keV correspond to time spread: 68 ps, 26 ps, 4ps, respectively.

The emerging positron beam from the end surface of the converter has wide energy spread, since the most of positrons cannot be thermalized in the converter. To separate these high-energy components, several apertures and a set of collimators will be equipped, since the high-energy components shift normal to the axis more at bending section.

4 CONCLUSION

To obtain high-density bunched positron beam, the new transport system based on the L-band linac at ISIR was designed in order to understand the behavior of Ps in materials. The new facility for this experiment was designed, and the number of positrons are expected to be about 1.1×10^{5} and the pulse width is 200 ps.

5 REFERENCES

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