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Simulation of a Polarimeter for a Spin-Polarized Positron Beam

J. H. Kim*†, F. Saito**, N. Suzuki**, L. Wei**, Y. Nagashima***, T. Kurihara****,
A. Goto**, Y. Itoh**, Y. S. Lee*****, and T. Hyodo***

**School of Chemical Engineering, Seoul National University, San 56-1, Kwanak-gu, Seoul 151-742, Korea*
***The institute of Physical and Chemical Research(RIKEN),*
2-1, Hirosawa, Wako-si, Saitama, 351-0198 Japan
****Institute of Physics, Graduate School Arts and Sciences, University of Tokyo,*
3-8-1 Komaba, Meguro-ku, Tokyo 153-8902, Japan
*****Institute of Materials Structure Science(IMMS),*
High Energy Accelerator Research Organization(KEK), Oho, Tsukuba, Ibaraki 305-0801, Japan
******Center for Science in Nanometer Scale(CSNS),*
Seoul National University, San 56-1, Kwanak-gu, Seoul 151-742, Korea

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Abstract

A performance of a new positron polarimeter is investigated by simulation using a charged-particle trajectory program. The results of the ray tracing are presented along with the details of the design parameters and projected system performance. A ray tracing analysis indicates that this design is capable of effectively transmitting positrons at beam energies varying from 0.1 to 30 keV within the beam diameter of 2-6 mm. However, the observed reflection of the positrons(lower than 2 keV) at 12 kGauss indicated that further refinement of beam design is needed to produce a better positron polarimeter.

1. Introduction

Recently spin-polarized low-energy positrons are considered as useful probes for studying of electron spin states of both surface and bulk materials [1,2] due to the spin-dependent interactions between electrons (e^-) and positrons (e^+), the formation of positronium (Ps). Gerber et al., [3] reported that the efficiency of positron polarimeters is of order 100 times larger over the standard electron polarimeter. Thus polarized positron can be used to determine the relative electron spin-state populations and even to take an image of magnetic domain structures with a sub-micron resolution. Because of the parity violation, the spin of positrons emitted from β-decay is polarized along their momenta direction (longitudinally). Nagai et al., [4] succeed to measure the polarization (~33%) of positrons from a ^{22}Na source using a positron spin polarimeter by means of magnetic quenching(Zeeman effects) of o-Ps. The magnetic quenching effect to be observed is a conversion of a certain amount of o-Ps decay to p-Ps decay [5] in the presence of an applied magnetic field. The spin-polarized high-energy positrons from beta decay that penetrate far below the surface have been used to study bulk magnetic properties [6].

In order to study the magnetism of surface and interface, a spin-polarized low-energy (~10 eV) beam of positrons will be employed in conjunction with an electrostatic system described in ref. [7]. The low-energy positrons can be transported by electrostatic lenses and made to focus at the sample under study in a controlled manner much like the electron beams. The

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† E-mail : jhkim68@snu.ac.kr

small penetration of low energy positrons(0.1 - 30 keV) into the sample enables us to study the interaction of positrons with surfaces and interfaces. However, only a few experiments [8,9] have been carried with monoenergetic spin-polarized positrons. Kumita et al. [8] have constructed a polarimeter based on lifetime measurement, indicating problems of positron reflection by mirror effect at the polarimeter.

In this paper, we design a new positron polarimeter and report the simulation results of its performance using a charged-particle trajectory program. The results of the ray tracing are presented along with the details of the design parameters and projected system performance. The positron polarimeter will be used in conjunction with an electrostatic system in which ^{18}F will be generated as a polarized positron source using azimuthal varying field(AVF) cyclotron at the Institute of Physical and Chemical Research(RIKEN) [7]. The polarization of slow positrons will be measured by an ortho-positronium quenching method with incident energies of 0.1 to 30 keV in the presence of magnetic fields(up to 12 kGauss). The design of the polarimeter enables the effective transmission of positrons to the sample by avoiding the reflection of the positrons using electrostatic lenses, which do not change the spin of positrons.

2. Schematic view of polarimeter

A schematic view of polarimeter is shown in Fig. 1. The accelerated(up to 30 keV) beam enters through a hole in one of the pole pieces of the magnet and focuses to the surface of amorphous SiO$_2$(or microchannel plate, MCP) target. The ortho-like Ps formed on the surface of the sample annihilates into(γ-rays, which are to be measured by a pure Ge Detector. The sample is placed at the center of the magnet, where a uniform magnetic field(up to 12 kGauss) will be applied along either parallel or antiparallel to the direction of the positrons (see Fig. 1). The polarization can be determined, as already shown its sensitivity [5], through the asymmetry in the populations of ortho-positronium(o-Ps) and para-positronium (p-Ps) formed in a-SiO$_2$ in the presence of static magnetic fields.

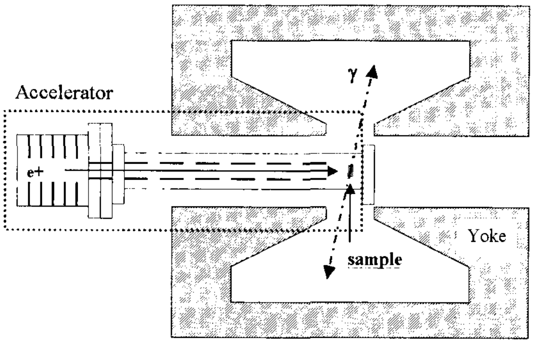

Fig. 1. A schematic diagram of the positron polarimeter. The gap distance of the two magnetic poles is set to 34 mm.

3. Simulation results and discussion

For the polarimeter shown in Fig. 2(inside of dotted rectangular of Fig. 1), slow positrons extracted from a parallel-plate analyzer are accelerated(0.1 - 30 keV) by a linear-type accelerator (1) and transported to a sample (2) through an electromagnet (5). Seven cylindrically symmetric lenses (3) with a 20 mm inner diameter are used to focus the positrons onto the sample through a hole in the electromagnet pole pieces, producing a

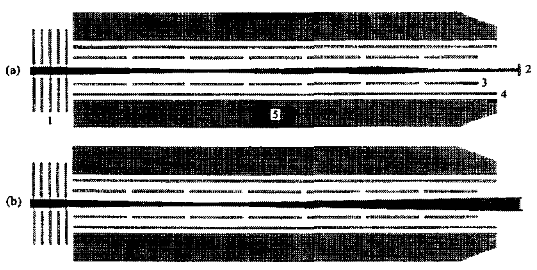

Fig. 2. Ray tracing simulation(with a charge particle trajectory program) of the polarimeter. (1) Accelerator, (2) sample, (3) lenses, (4) chamber, and (5) electromagnet. The beam profiles are shown using the lenses to focus (a) and without using the lenses (b) at the incident energy of 4 keV, indicating that the beam diameter at the sample can be reduced from 11 mm to 2 mm.

magnetic field. The beam profiles shown in Fig. 2 using the lenses to focus (a) and without using the lenses (b) at the incident energy of 4 keV, indicate that the beam diameter at the sample can be reduced from 11 mm to 2 mm. For the rays representing positrons leaving the moderator, we have chosen 33 trajectories(ranging from -80° to +80°), which are evenly spaced on the moderator with a diameter of 6mm in x-y plane.

As shown in Fig. 3, the beam diameter(open squares) exponentially increases as the beam energy decreases and thus the positrons will hit out of the sample when the beam energy is lower than 4 keV. Using the lenses, positrons can be focused on to the sample with the beam diameter(closed circles) of 2-6 mm in the range of beam energies from 0.1 to 30 keV in the case of no magnetic field applied at the target. The focusing effect makes the measurement extend to the range of beam energies from 0.1 to 30 keV.

The reflection of the positrons due to the mirror effect is simulated as a function of the beam energies (0.1 - 30 keV) and magnetic fields(0 - 12 kGauss). The profile of 1 keV positrons with 6 kGauss at the sample(Fig. 4(a)), indicates that some of positrons reflect due to mirror effect and annihilate at somewhere else from the sample, which will cause a serious background or leads a false signal. For the comparison, Fig. 4(b) shows the beam profile of 1 keV positrons with no magnetic applied. Without using the small lenses, the reflection of the positrons occurs at beam energies of less than 5 keV, even under weak magnetic fields (left side of the dotted line in Fig. 5). Focusing the positrons using lenses, as indicated by the solid line, can reduce

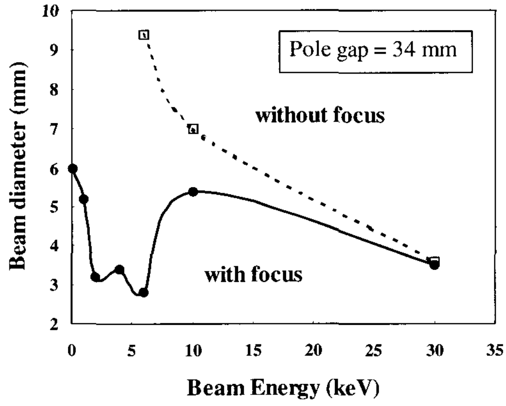

Fig. 3. The beam diameter at the sample as a function of beam energies. The open squares represent the diameter without focusing while the closed circles represent the diameter with focusing.

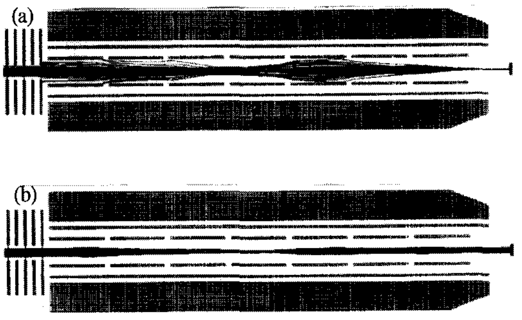

Fig. 4. The magnetic field dependence of the profile for 1 keV positrons. The reflection of the positrons due to the mirror effect is simulated as a function of the beam energies(0.1 - 30 keV) and magnetic fields(0 - 12 kGauss). The profile of 1 keV positrons with 6 kGauss at the sample (a), indicates that some of positrons reflect due to mirror effect and annihilate at somewhere else from the sample. For the comparison, (b) profile indicates no mirror effect.

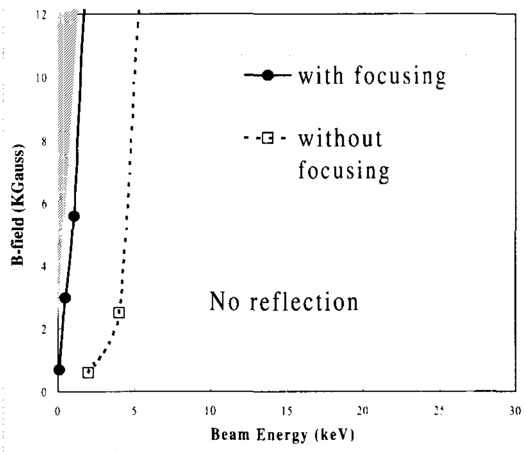

Fig. 5. Magnetic field dependence of the beam reflection as a function of beam energies.

the mirror effect(shaded area). The reflection of the positrons, however, observed below the beam energy of 2 keV at 12 kGauss indicated that further refinement of beam design is needed to produce a better positron polarimeter.

Summary

In this paper, we have presented the design considerations and the results of computer simulations for a positron polarimeter. A ray tracing analysis indicates that this design is capable of effectively transmitting positrons at beam energies varying from 0.1 to 30 keV within the beam diameter of 2-6 mm. However, the observed reflection of the positrons(lower than 2 keV) at 12 kGauss indicated that further refinement of beam design is needed to produce a better positron polarimeter. Spin polarized positrons have recently been applied to find the origins of biological chirality [10] and to probe the spin polarization of electrons at the surface of Ni(110) [9], including polarized low-energy positron diffraction(PLEPD) as a complement to polarized low-energy electron diffraction.

Acknowledgments

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