Spin polarizations of positron beams generated using electrostatic and magnetic transportation systems with ^{68}Ge and ^{22}Na sources

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Spin polarizations of positron beams generated using electrostatic and magnetic transportation systems with ^{68}Ge and ^{22}Na sources

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Abstract. Spin polarizations of electrostatic positron beams generated using ^{68}Ge and ^{22}Na sources with tungsten moderators were 47 % and 30 %, respectively. A comparable spin polarization (27 %) was obtained with much reduced beam diameter (0.5 mm), when electromagnetic lenses, a ^{22}Na source and a tungsten moderator were used. Replacing the tungsten moderator with a solid neon moderator in this system, the beam flux was significantly enhanced with maintaining the spin polarization. The Doppler broadening of annihilation radiation spectra of polycrystalline Fe measured using the above beams showed clear asymmetry upon field reversal.

1. Introduction

The pair-annihilation probability of positron and electron charges depend on their relative spin directions. Therefore, if both positrons and electrons are spin-polarized, positron-electron momentum distribution shows asymmetry upon spin reversal. We proposed that the Doppler broadening of annihilation radiation (DBAR) technique with spin-polarized positrons can be used for studying ferromagnetic band structures [1, 2]. Such spin-polarized positron annihilation spectroscopy (SP-PAS) will be a potential tool in current spintronics study. Considering the fact that novel spin-phenomena occur at surfaces and interfaces and in thin films, a spin-polarized positron beam needs to be developed [3-5]. To obtain a highly spin-polarized positron beam, it is important to use β^+-emitters with higher energy endpoints (E_{max}). We have demonstrated the spin polarization of an electrostatic positron beam using a ^{68}Ge isotope (E_{max} = 1.9 MeV) was 47 % [6, 7]. In this study, we first compare the spin polarizations of positron beams using ^{68}Ge and ^{22}Na sources in electrostatic transportation systems. We also examined the spin-polarization of the positron beam generated by ^{22}Na source, magnetic lenses and tungsten/solid neon moderators.

2. Positron beam apparatus

Four types of positron beam apparatus were constructed: (i) ^{68}Ge source + tungsten moderator + electrostatic transportation, (ii) ^{22}Na source + tungsten moderator + electrostatic transportation, (iii) ^{22}Na source + tungsten moderator + electromagnetic transportation and (iv) ^{22}Na source + solid neon moderator[8, 9] + electromagnetic transportation. These are schematically summarized in figure 1 and 2. The source strengths and moderator details are also listed in table 1.

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The longitudinal spin polarizations of the above positron beams were measured from the magnetic quenching of the positronium in fused silica, which is simpler method than measuring the positronium decay rate[7, 10, 11]. The strength and direction of the magnetic field were controlled by changing the permanent magnets. Furthermore, the Doppler broadening of the annihilation radiation spectra of polycrystalline Fe were also measured.

3. Results and discussion

The magnetic field dependences of S parameters from the fused silica and estimated spin polarizations

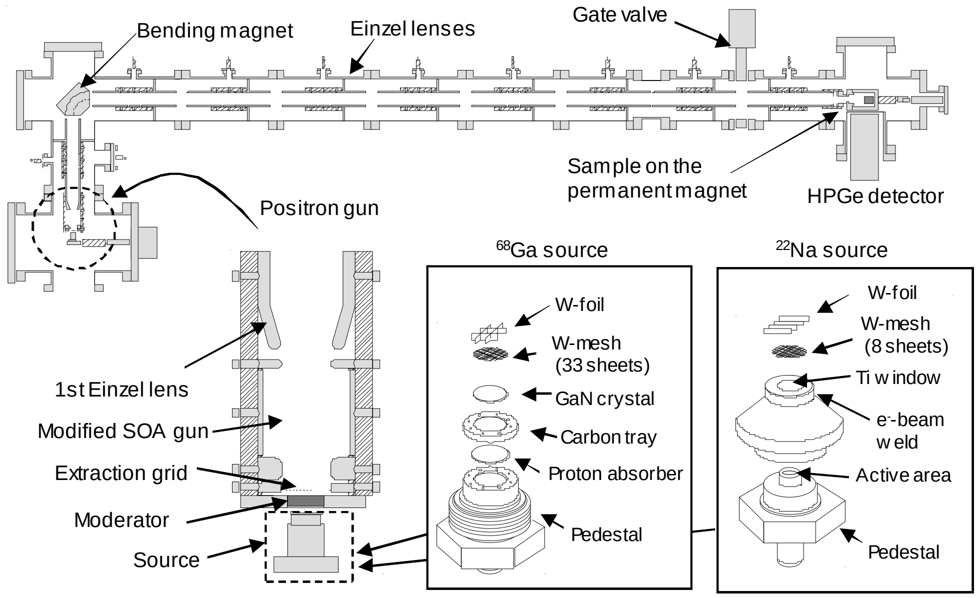

Figure 1. Schematics of the apparatus using ^{68}Ge and ^{22}Na source with the tungsten moderator and electrostatic lenses : type (i) and (ii).

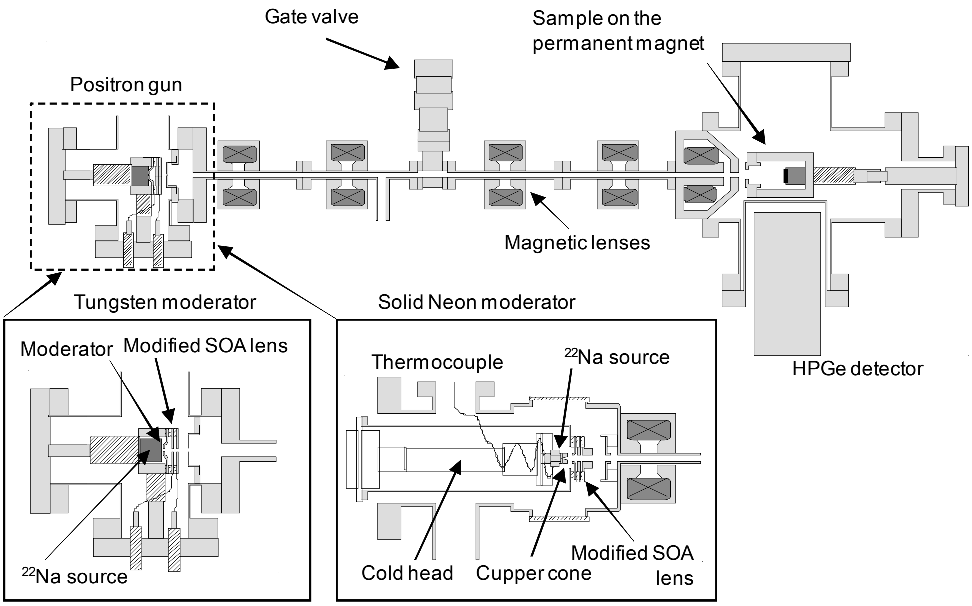

Figure 2. Schematics of the apparatus using magnetic lens transport: type (iii) and type (iv).

for each beam are shown in figure. 3. The spin polarization of the type (i) positron beam is estimated to be 47 ± 8 %, which is in good agreement with the theoretical calculation. Details of this analysis is described in the previous paper [7]. This value is ~20 % higher than that of the type (ii) ^{22}Na-based positron beam (30 ± 3 %). From this result, the ^{68}Ge source is superior to the ^{22}Na source.

In the case of the electromagnetic beam transport, spin polarization is expected to be lost due to the fringing magnetic field, which is across to the beam trajectory. However, spin polarizations of type (iii) and (iv) beams are 28 ± 4 % and 27 ± 4 %, respectively, that are comparable to the case of electrostatic beam (type (ii)). Probably, since the directions of the positron spin and magnetic fields of magnetic lenses are parallel, the fringing fields are relatively weak near the beam axis. In the electromagnetic beam systems, the beam diameter is better focused (0.5 mm in diameter) as compared to the electrostatic systems (2~5 mm). Furthermore, when solid neon moderator was used (type (iv)), the positron beam intensity is much higher than in the case of tungsten moderator. Thus, in the electromagnetic system, without losing longitudinal spin polarization, much better positron beam is obtained.

Figure 4 shows the differential DBAR spectra of a well-annealed Fe sample in a magnetic field. This differential spectra $[N_{\uparrow}(p)-N_{\downarrow}(p)]$ was obtained by altering the field polarity. The subscript ↑ or ↓ indicates whether the positron polarization and the magnetic field direction was parallel or anti-parallel. The finite differential intensity means that there is a field-reversal asymmetry, which arises from the enhanced annihilation between the spin-up positrons and spin-down 3d unpaired electrons [12,13]. The differential amplitude of (b) is almost 2.3 times higher than that of (a). This is because the differential amplitude of the differential DBAR spectra is proportional to the sample magnetization and the positron spin polarization[1] (0.91T/0.55T × 47%/30% ≅ 2.5). This result also shows that our positron beam was sufficiently spin-polarized.

4. Summary

From the comparison between two electrostatic positron beams using ^{68}Ge and ^{22}Na sources, it is concluded that sources with higher energy endpoints are preferred in generating highly spin-polarized positron beams. Electromagnetic transportation is suitable to generate well focused and longitudinally

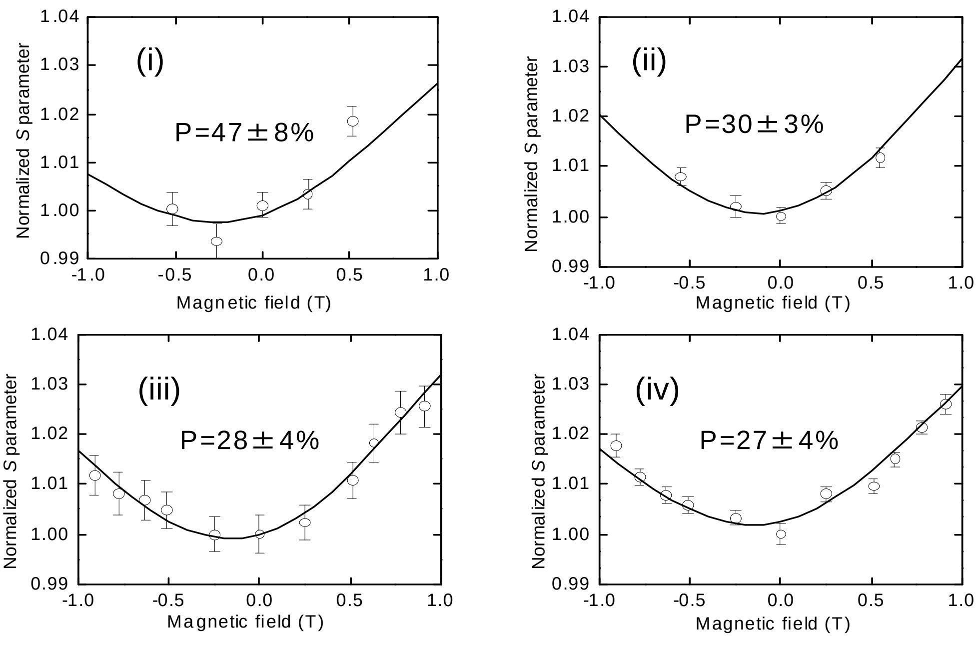

Figure 3. The magnetic field dependences of S parameters from a fused silica obtained using the slow positron beams of the apparatus type (i)~(iv). Theoretical curves of best fitting and estimated spin polarizations are also shown.

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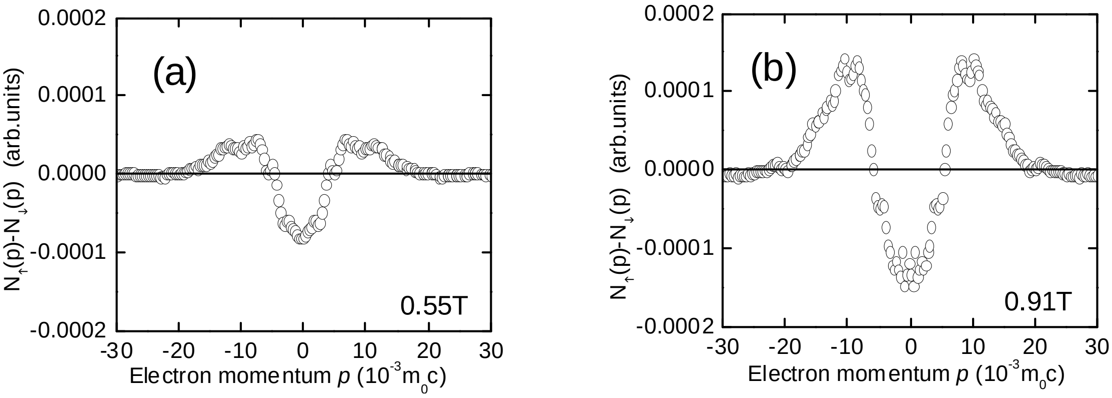

Figure 4. Differential DBAR spectrum of the well-annealed Fe sample in a magnetic field. (a) and (b) were obtained using type (i) and (iv) apparatus, respectively.

Table 1. Positron beams and their spin polarization.

Type	Source	Moderator	Transpotation	Flux (e^+/s)	Spin polarization (%)
(i)	^{68}Ge (250 MBq)	Tungsten mesh (33 sheets)	Electrostatic	~2×10^3	47 ± 8
(ii)	^{22}Na (20 MBq)	Tungsten mesh (8 sheets)	Electrostatic	~2×10^3	30 ± 3
(iii)	^{22}Na (220 MBq)	Tungsten mesh (16 sheets)	Magnetic	~1×10^3	28 ± 4
(iv)	^{22}Na (88 MBq)	Solid neon	Magnetic	~8×10^4	27 ± 4

spin-polarized positron beam. Positron beam generated using solid neon moderator has a comparable spin polarization to that using tungsten moderator.

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