Development of spin-polarized slow positron beam using a new ^{68}Ge–^{68}Ga/GaN positron source and its application for positron annihilation spectroscopy

M. Maekawa, Y. Fukaya, H. Zhang, H. Li and A. Kawasuso
R.G. for Spin-Polarized Positron Beam, JAEA

Positrons emitted from radioisotopes are longitudinally spin-polarized due to the parity non-conservation in the weak interaction. Positron annihilation studies have shown that the ferromagnetic band structure can be investigated using the Doppler broadening of annihilation radiation (DBAR) technique with spin-polarized positrons [1,2]. Considering the fact that various novel spin phenomena have recently been found to occur at surfaces/interfaces and in thin films, spin-polarized positron beams is useful in spintronics studies. We developed a highly spin-polarized beam from a new ^{68}Ge–^{68}Ga source.

The spin polarization of positrons emitted from a positron source P is given by

$$P = \frac{v}{c}\frac{(1-\cos\theta)}{2},$$

here v is the positron speed, c is the speed of light and θ is an open angle in a specific direction [3]. This equation suggests that positron sources with a higher energy end-point are better for generating highly spin-polarized positron beams.

The ^{68}Ge–^{68}Ga positron source has relatively long half-life and higher energy end-point (288 days and 1.9 MeV). In addition, higher cross section (0.465×10^{-24} cm^2 at E_{proton} = 20 MeV) of nuclear reaction ^{69}Ga(p, 2n)^{68}Ge allows the source production using ion beam. Figure 1 shows schematic diagrams of the source capsule. High-purity metal ^{69}Ga should be used as a target material, however, metal Ga is molten during irradiation because of its low melting point (29 °C). Such molten Ga reacts with the other metal components of the source capsule and eventually destroys the capsule. To avoid this problem, we propose GaN as a target material, although the amount of ^{69}Ga(p, 2n)^{68}Ge is decreased. To avoid metallization during irradiation, the GaN target was placed in a carbon tray. The target was directly irradiated with 20 MeV proton beam with a maximum current of 3.5 μA using the cyclotron at the Takasaki Advanced Radiation Research Institute. The efficiency of the source production was estimated to be 0.5 MBq/μA/h from the gamma ray energy spectrum. This was in good agreement with the results from our simulation. The irradiation was carried out over 400 h in total.

The positrons emitted from the GaN target were moderated by a tungsten mesh moderator. The slow positrons extracted by a grid electronode were transported to the sample position by an electrostatic system in order to avoid the depolarization during the beam transportation.

Consequently, a positron beam with a diameter of 5 mm and a flux of 5×10^{3} e^{+}/s was obtained with the positron energy of E=5~15 keV. The spin polarization of the positron beam was determined to be 47 ± 8% from the magnetic quenching of the positronium in fused silica [4]. Thus, it is important to use positron sources with higher energy end-points to generate highly spin-polarized positron beam.

The field-reversal asymmetry of the DBAR spectra for ferromagnetic Fe was measured using the positron beam. Figure 2 shows the differential DBAR spectra in a magnetic field of 0.55 T [4]. The differential DBAR spectra [$N_{\uparrow}$(p) and $N_{\downarrow}$(p)] were obtained by altering the field polarity. 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 [5]. This also shows that our positron beam was sufficiently spin-polarized.

In summary, we produced a ^{68}Ge–^{68}Ga/GaN source by irradiating a GaN target with proton beam and a spin-polarized positron beam was generated using this source. Measurements of the DBAR spectra of fused silica and ferromagnetic Fe in magnetic field demonstrated that the beam was sufficiently spin-polarized.

This work was supported by JSPS KAKENHI Grant No. 24310072.

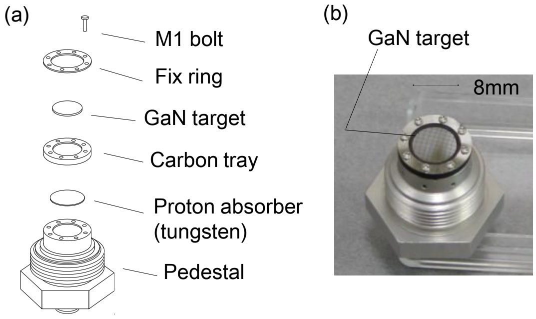

Fig.1 (a) Schematic and (b) photograph of the source capsule.

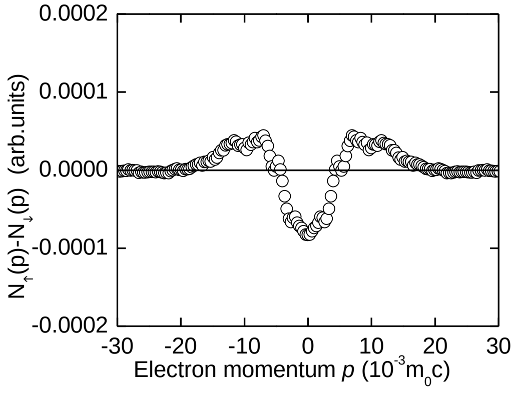

Fig.2 Differential DBAR spectra of Fe sample obtained in the external magnet field of 0.55 T.

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