Applied Surface Science 194 (2002) 43–46

applied surface science

www.elsevier.com/locate/apsusc

Improvement of the electrostatic positron beam apparatus and observation system for RHEPD experiment

T. Ishimoto*, A. Kawasuso, H. Itoh

Japan Atomic Energy Research Institute, Takasaki Establishment, Watanuki, 1233, Takasaki, Gunma, 3700-1292, Japan

Abstract

We have observed reflection high energy positron diffraction (RHEPD) using the electrostatic positron beam apparatus, where positrons were accelerated at 20 keV and converged using three einzel lenses and a collimator. To reduce beam energy dispersion and gamma ray background, a 45° electrostatic prism and einzel lenses were newly added to the original apparatus. The positron beam is further collimated to 1 mm diameter. Final beam energy dispersion and angular divergence are less than 0.1 keV and 0.1°, respectively. Any noises arising from the gamma rays are not observed. We also fabricated the positron beam observation system with a dynamic range of approximately 4.3×10^9. The above improvements enabled to detect the fine structures of diffraction patterns and rocking curves.

Keywords: Positron diffraction; RHEPD; Electrostatic positron beam

1. Introduction

We succeeded in observing the zeroth Laue pattern of reflection high energy positron diffraction (RHEPD) using a paraxial beam with a collimator [1]. This method has been applied for several surface studies so far. However, the first Laue pattern and any fractional order spots were not observed. One reason is that the positron beam energy dispersion was not small enough due to high energy positrons from the source. If energy dispersion is large, it is difficult to observe weak structures in diffraction pattern because of diffusion of spots. The coherence distance is given by $L = 2\,E\lambda/\Delta E$, where E is the beam energy, λ the wavelength of positron beam, and ΔE the beam energy dispersion. For example, if energy dispersion is 10%, a surface structure in which the size of unit cell is greater than 2 Å is hardly observed. In addition, high energy gamma rays from positron source decreased the S/N ratio of the image plate. The S/N ratio must be enhanced because the first Laue pattern intensity is much weaker than the zeroth Laue pattern.

In order to observe the first Laue pattern and fractional order spots, our original apparatus [1] has been improved by introducing a 45° electrostatic prism and einzel lenses. To enable integration of diffraction pattern images for long hours without saturation, we fabricated an observation system with a wide dynamic range.

2. New apparatus and observation system

The original beam apparatus was composed of a positron gun based on the Brandeis method with a 370 MBq sodium-22 positron source, a tungsten moderator (5 μm thick) and three einzel lenses [1]. Using a collimator, we extracted a paraxial beam. Positrons are

* Corresponding author. Tel.: +81-27-346-9330; fax: +81-27-346-9687.
E-mail address: ishimoto@taka.jaeri.go.jp (T. Ishimoto).

0169-4332/02/$ – see front matter
PII: S0169-4332(02)00086-7

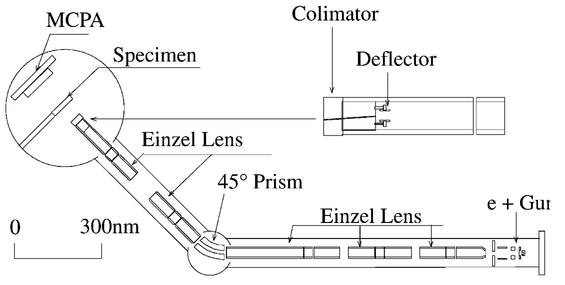

Fig. 1. Schematic diagram of the improved positron beam apparatus.

accelerated up to 20 keV. Fig. 1 shows a schematic diagram of the new apparatus. A 45° electrostatic prism and two einzel lenses were added after the third einzel lens in the previous beam line. The prism is hemispherical type deflector. The separation between the positive and negative electrodes is 10 mm. Two metal plates are put at the front and the rear parts of the prism for the correction of electric field. The slit width of the field correction plate is 5 mm. The focal point of the beam can be set in front of the following einzel lens. The positron beam is further focused and transported by two einzel lenses after the prism. Inner diameter of the einzel lens is 30 mm, which is same as the previous design. The first and third electrodes of the einzel lens are grounded and the second electrode is electrically floated. Thus, the beam energy is not changed by the einzel lenses. Before the collimation, the beam is deflected by 4.4°. The deflected beam is transported into the collimator with a pinhole size of 1 mm. Although the nominal beam energy dispersion after the prism is calculated to be ±1.6 keV (8%), this is expected to be further reduced due to the extension of beam transportation.

Fig. 2 shows the positron beam images observed by the microchannel plate assembly (MCPA). It is found that the beam diameter can be reduced by changing the electric field as shown in Fig. 2(a) and (b). Position of the center of the beam was not shifted by changing the field of the lenses. This means that the axis of lenses is almost the same as that of the beam. High energy positrons from the source are removed by the prism and any noises arising from the gamma rays are not observed at MCPA. Fig. 2(c) shows the beam image after the collimation. It is found that the beam is well collimated as expected. Angular divergence was measured to be less than 0.1° from the change of beam diameter at different MCPA positions.

The beam energy dispersion is determined from the dependence of the collimated beam intensity on the deflector voltage in front of the collimator as follows. As the deflector voltage increases the beam intensity starts to increase at a threshold voltage and has a maximum at a certain voltage. The deflector voltage for the maximum beam intensity is deduced from a condition that the deflection and collimator angles are the same. The threshold deflector voltage is determined by considering the diameter of the collimator. For the beam energy of 20 keV, the threshold deflector voltage appears at −355 V from the voltage for maximum beam intensity. If the beam energy dispersion is 1%, this value shifts by 10 V to lower side. Fig. 3 shows the dependence of the beam intensity after the collimator on the deflector voltage. Here, the deflector voltage for maximum beam intensity is set to be zero. The threshold voltage for the increase of beam intensity is comparable to the ideal value (−355 V). Thus, the beam energy dispersion is less than 1.0% at most.

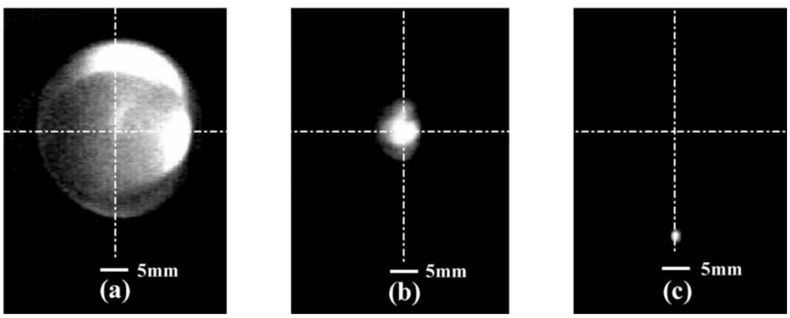

Fig. 2. Positron beam images at (a) defocus, (b) focus modes without collimation and (c) after collimation.

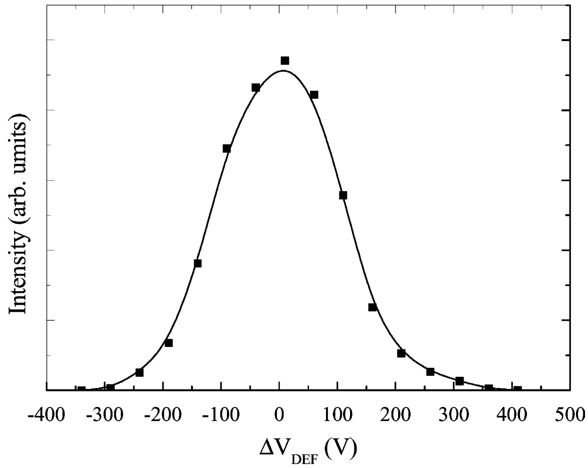

Fig. 3. Intensity of beam through collimator as a function of the deflection voltage. The deflection voltage for the maximum beam intensity is set to be zero.

The dynamic range of previous system was about 3.3×10^4. This is too narrow to measure intensity of the higher order Laue pattern with high statistics. Thus, the dynamic range of observation system must be enhanced. Fig. 4 shows the observation system fabricated here. We use a directly memory access (DMA) image capture board installed in the personal computer (PC) and the charge-coupled device (CCD) camera of the Peltier cooling type. The lowest object illuminance of this CCD camera is 2.5×10^{-4} lx. Analog signal

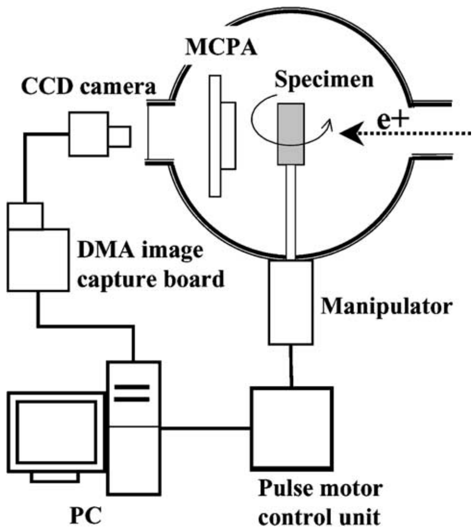

Fig. 4. Schematic diagram of positron beam observation system.

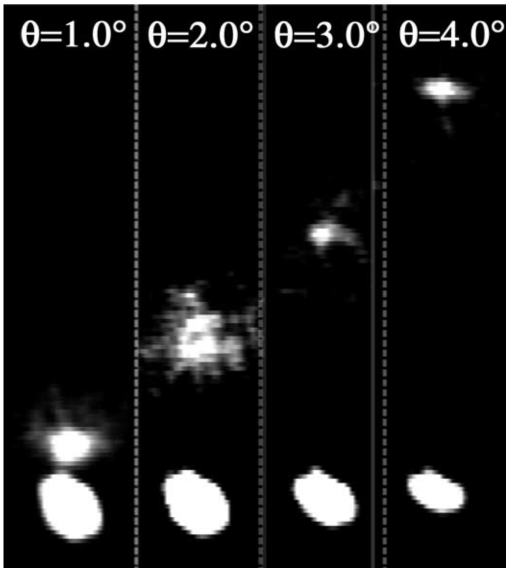

Fig. 5. Specular spot observed for Si(1 1 1) surface at different glancing angle.

from the CCD camera is converted to digital image as 8 bits data by a DMA image capture board. The digital data are saved into a memory and integrated by the PC. To prevent dropping of image data during integration, memory area is divided into some domains. Then digital data are saved at each domains continuously so that the image data are integrated with a rate of 30/s. In order to obtain the wide dynamic range, the integrated image data is finally saved as 32 bits, i.e. the dynamic range becomes to be 4.3×10^9. This dynamic range is large enough for the long time observation without saturation. The above observation system is linked with a manipulator, which controls the glancing angle of positron beam. Thus, RHEPD pattern can be automatically taken at arbitrary glancing angles. Fig. 5 shows the shift of the specular spot due to the change of glancing angle for Si(1 1 1) surface. It is found that the specular spot moves to upward with a constant rate. By calculating this constant rate, we obtain the glancing angle dependent specular intensity.

3. Summary

We improved the electrostatic positron beam apparatus for RHEPD by adding a 45° electrostatic prism and two einzel lenses. The positron energy dispersion and angular divergence are less than 0.1 keV and 0.1°, respectively. Any noises arising from the gamma rays are not observed. The dynamic range of the observation system is 4.3×10^9. This allows us to integrate image data for long hours without saturation.

Reference

[1] A. Kawasuso, S. Okada, A. Ichimiya, Nucl. Instrum. Methods Phys. Res. B 171 (2000) 219–230.