Development of intense ^{7}Be beam for wear diagnostics of industrial materials

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The industrial cooperation team and SHIEI Ltd.*1 are developing a new method for wear diagnostics of industrial material using RI beams as tracers. RI nuclei are implanted in a near surface of the machine parts within depth of 10-100 μm, and its wear-loss is evaluated by the decrease in the measured radioactivity. Continuous γ-ray detection from the exterior of the machine enables real-time diagnostics of wear in running machines. For this purpose, RI nuclei having sufficiently long lifetime are desired. At present, we can provide an intense ^{22}Na ($T_{1/2}$ = 2.6y) beam at RIPS separator[1]. On the other hand, CNS*2 group has developed a cryogenic gas target system[2] at CRIB*3 separator and reported production of an intense ^{7}Be ($T_{1/2}$ = 53d) beam using the system. With the aim to utilize this intense ^{7}Be beam for the wear diagnostics, a beam study managed by industrial cooperation team was performed.

A primary beam of $^7Li^{2+}$ was accelerated by the AVF cyclotron up to 39.9 MeV (5.7 MeV/nucleon) with a maximum intensity of 1.2 particle μA (pμA). The ^{7}Be beam was produced via p(^{7}Li,^{7}Be)n reaction at the cryogenic gas target. The H_2 target gas was confined in a gas cell (8 cm long and 2 cm in diameter) sealed by 2.5-μm-thick Havar foils. The H_2 gas at a pressure of 760 Torr was cooled by liquid N_2 in a vessel at 90 K and circulated to the gas cell at a rate of 55 slm. The primary beam was focused on a Havar foil placed at entrance of the gas cell with the spot size of 1 mm in diameter. The target was very stable during this experiment. The produced ^{7}Be beam was introduced to the F2 focal plane without degrader foil at F1. In order to enable ^{7}Be implantation under air pressure condition, the vacuum chamber at F2 was modified so that a vacuum-separation foil could be attached. First, under a vacuum condition, the profiles of secondary beams were measured at F2 using a PPAC and a silicon detector. The energy and radius of the $^7Be^{4+}$ beam was 28.7 MeV (4.1 MeV/nucleon) and σ = 6.1 mm, respectively, with a momentum slit of ± 3.1% (± 50 mm) at F1. A contaminant nuclide of $^7Li^{3+}$ was observed with a fraction of 20% and energy of 18.8 MeV. Second, a Kapton vacuum-separation foil (50 μm thick and 5 cm in diameter) was assembled, and He gas at 1 atm was filled in the F2 chamber. The distance from the foil to the irradiation position was 14 cm. The ^{7}Li contaminant was stopped in the He gas, completely. The remainder of the ^{7}Be beam was 100% in purity and its peak energy was 13.5 MeV, with a width of σ = 1.6 MeV. The intensity of the ^{7}Be beam was 1.9 × 10^8 pps obtained by the following γ-ray measurement, which reproduced a reported value in the Ref.2.

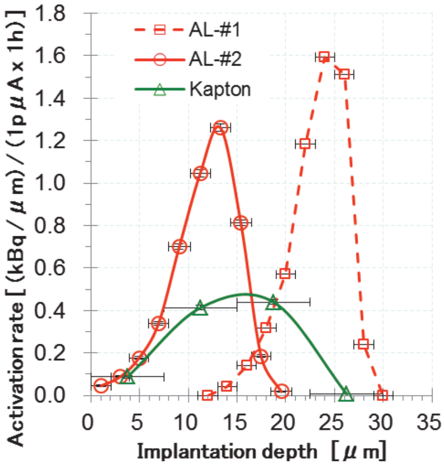

Fig. 1. Implantation-depth profile of thin-foil stacks.

To investigate the implantation-depth profile of ^{7}Be, two sets of thin-foil stack with a diameter of 16 mm were irradiated. One was a stack of 2-μm-thick aluminum foils and the other was a stack of 7.5-μm-thick Kapton foils. After irradiation, each stack was disassembled and the intensity of the γ ray (E_γ = 478 keV) was measured using a Ge detector. First, the range profile of the above-mentioned ^{7}Be beam was measured using the aluminum-foil stack (AL-#1). Then, in order to control the implantation depth to near the surface, a rotating energy degrader was introduced. An 8-μm-thick aluminum foil was set on the beam path at 50° (corresponding to a thickness of 10.4 μm) and 90°, alternatively, relative to the beam axis with a time fraction of 5:1. The second aluminum-foil stack (AL-#2) and the Kapton-foil stack were irradiated under this condition. The obtained implantation-depth profiles are shown in Fig.1. In this figure, the ^{7}Be activation rate (kBq/μm) is normalized by the dose of the ^{7}Li primary beam (1 pμA × 1 h irradiation). X-error bars indicate the thickness of each foil, and Y-error bars indicate the statistical error in this measurement. From this result, we could achieve peak activity of 1.3 and 0.5 kBq/μm at depth of 13 and 15 μm from the surface of the aluminum and Kapton material, respectively. For example, when we measure the wear-loss of an aluminum machine part (case AL-#2), we can obtain peak activity density of 13 kBq/μm for 10-h irradiation. Since the best wear-loss sensitivity can be achieved near the depth of the maximum activity density, it would be required for actual applications to locate the peak of the activity distribution near the depth of interest for the wear-loss analysis.

References

1) T. Kambara et al.: AIP Conference Proceedings 1412, 423−429 (2011).
2) H. Yamaguchi et al.: NIM A589, 150−156 (2008).

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