ISSN 1343-2230

CNS-REP-93
March, 2015

Annual Report
2013

Center for Nuclear Study,
Graduate School of Science, the University of Tokyo

Irradiation of ^{7}Be and ^{22}Na beams for wear diagnostics application

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In order to develop a method for wear diagnostics of industrial material using RI beams as tracers [1], irradiation experiments of intense ^{7}Be and ^{22}Na beams were performed using CRIB facility. These experiments were scheduled under the collaborative research agreement among RNC, CNS and private companies. RI nuclei are implanted in a near surface of the machine parts, and its wear-loss is evaluated by the decrease in the measured radioactivity. Continuous detection of γ rays from the outside of the machine enables real-time diagnostics of wear in running machines. For this purpose, intense beams of RI nuclei ^{7}Be ($T_{1/2}$ = 53d) and ^{22}Na ($T_{1/2}$ = 2.6y) were provided using CRIB.

The ^{7}Be beam was produced via $p(^7\mathrm{Li},^7\mathrm{Be})n$ reaction. A primary beam of $^7\mathrm{Li}^{2+}$ with the energy of 5.7 MeV/u and intensity of 1.7 $particle$ μA (pμA) in average was introduced to the cryogenic H_2 gas target. 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 30 slm. The calculated energy loss in the gas target was 1.4 and 5.9 Watt at the exit Havar foil of 2.5 μm in thickness and in the target gas, respectively. During two days experiment, the target was stable, but the primary beam intensity was a bit unstable. CRIB control program became unresponsive two times, it seems related to high radiation dose of neutron caused by the RI beam production reaction. The produced ^{7}Be beam was introduced to the F2 focal plane without degrader foil at F1. At the F2 focal plane, a dedicated vacuum chamber fabricated by the industrial cooperation team (RNC) was installed. A position sensitive Si-detector (PSD, Hamamatsu S5378-02), a rotating energy degrader and a rotating irradiation sample holder were installed in the chamber. The profiles of secondary beams were measured using the PSD detector. The energy and beam spot size of the $^7\mathrm{Be}^{4+}$ beam was 29.1 MeV (4.16 MeV/u) and 4.8×8.1 mm in fwhm, respectively, with a momentum slit of ± 3.1% (± 50 mm) at F1. The beam spot size was a bit large. It seems related to a halo of beam spot at the gas target. The implanted dose rate of the ^{7}Be beam was 60 kBq/h, approximately, obtained by the following γ-ray measurement.

The ^{22}Na beam was produced via the $p(^{22}\mathrm{Ne},^{22}\mathrm{Na})n$ reaction. A primary beam of $^{22}\mathrm{Ne}^{7+}$ with energy of 6.1 MeV/u and intensity of 0.25 pμA in average was introduced to the gas target. The H_2 gas at a pressure of 400 $Torr$ was cooled to 90 K and circulated to the gas cell at a rate of 20 slm. The calculated energy loss in the gas target was 2.1 and 4.5 Watt at the exit Havar foil and at the target gas, respectively. The Havar foil was broken when the primary beam intensity exceeded 0.30 pμA. During three days experiment, the primary beam intensity was almost stable, but the CRIB control program became unresponsive two times. The produced ^{22}Na beam was introduced to the F2 focal plane without degrader foil at F1. The energy and size of the $^{22}\mathrm{Na}^{11+}$ beam was 80.8 MeV (3.67 MeV/u) and 4.7×4.3 mm in fwhm, respectively, with a momentum slit of ± 3.1% (± 50 mm) at F1. The implanted dose rate was 0.3 kBq/h, approximately.

In order to control the implantation depth close to the surface, a rotating energy degrader (Fig.1) was newly introduced. Eight sets of aluminum foils can be mounted on a rotating wheel of 14 cm diameter. The wheel rotates with 12 rpm in speed using a vacuum motor. A beam collimator of 10 mm diameter is assembled at the down-stream of the wheel and a fixed-thickness degrader foil can be mounted on it. The stability of the secondary beam intensity was monitored by measuring a current from the collimator using a pico-ampere meter during the irradiation.

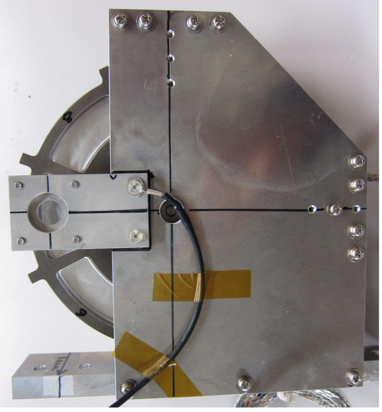

Figure 1: Rotating energy degrader unit.

To investigate the implantation-depth profile, a stack of 2-μm-thick aluminum foils were irradiated. After irradiation, the stack was disassembled and the intensity of the γ ray was measured using a Ge detector. As an example, ^{22}Na beam of narrow momentum distribution (± 1 % at F1) was irradiated to the stack passing through seven sets of aluminum degrader foils; 4.9, 7.6, 11.9, 16.9, 23.8, 27.4, 31.7 μm in thickness. An obtained depth profile is shown in Figure 2. The black circles indicate a normalized fraction of each Al-foil measured by the stacked foil method using the Ge detector. The X and Y error bars indicate the thickness and the statistical error of each Al-foil data point. The range of ^{22}Na beam in aluminum is calculated by the SRIM code [2] using a measured beam energy spectrum obtained by the PSD detector. The dotted line is the continuous range spectrum. Below 5 μm in thickness, the range spectrum could not be measured as it was below the detector threshold, unfortunately. The triangles indicate a normalized fraction of each Al-foil calculated by re-binning of the continuous range spectrum. Here, a factor of 0.97 was applied for the stopping power calculated by the SRIM code, and then a good agreement between the data points of Ge and PSD was obtained. We can conclude that the energy measurements using a Si detector gives a continuous implantation-depth profile with good accuracy.

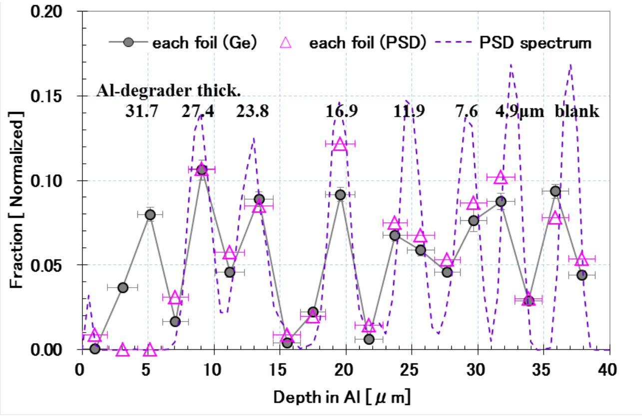

Figure 2: Implantation-depth profile of ^{22}Na beam into a stacked aluminum foils. The X error bars indicate the thickness of each foil as 2 μm, approximately.

The accuracy of this implantation-depth profile is the most important data for successive wear-loss diagnostics. The conventional stacked foil method is reliable, because it directly measures implanted dose in the material. But it has a limitation for depth-resolution. The resolution depends how thinner foils with same implantation material we can provide. Even though the thin foils are provided, the assembling of many thin foils as a stack is a hard work. On the other hand, the energy measurement using Si detector is simple, but it should rely on a range calculation. Here, we should introduce a small correction factor for the stopping power of unstable ^{22}Na beam in aluminum calculated by the SRIM code. But we can determine the factor experimentally using the pulse-shaped depth profile beam mentioned above. Thus, a precise measurement of implantation-depth profile can be performed using Si detector and the SRIM code calibrated by the stacked foil method.

Acknowledgements

A.Y. acknowledges GARIS Team (RNC) and G-Tech Co. Ltd. for designing the rotating energy degrader unit.

References

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