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

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To develop a method for wear diagnostics of industrial material using RI beams,[1,2] intense beams of ^{7}Be ($T_{1/2} = 53$ days) and ^{22}Na ($T_{1/2} = 2.6$ years) provided by CRIB were implanted in the surface of machine parts. Here we describe the generation and characterization of the RI beams.

The ^{7}Be beam was produced via H(^{7}Li,^{7}Be)n reaction. A beam of 5.7 MeV/A ^{7}Li^{2+} with an average intensity of 1.7 particle μA (pμA) was introduced to CRIB and passed through a cryogenic H_2 gas target at a pressure of 760 Torr and cooled by liquid N_2 to 90 K. The produced ^{7}Be^{4+} beam was introduced to a dedicated vacuum chamber at the F2 focal plane. A position-sensitive Si detector (PSD, Hamamatsu S5378-02), an energy degrader, and a rotating irradiation sample holder were installed in the chamber. The energy and profile of the RI beam were measured using the PSD. The energy of the ^{7}Be beam was 4.16 MeV/A, and the beam spot size was 4.8×8.1 mm in FWHM when the momentum spread was set to ± 3.1 %. The relatively large beam-spot size seems related to a halo of the beam spot at the gas target. The implantation rate of the ^{7}Be beam was approximately 60 kBq/h, according to a gamma-ray measurement after the implantation.

The ^{22}Na beam was produced via the H(^{22}Ne,^{22}Na)n reaction. A 6.1 MeV/A ^{22}Ne^{7+} beam with an average intensity of 0.25 pμA was introduced to the H_2 gas target at 400 Torr and 90 K. The energy and size of the ^{22}Na^{11+} beam at F2 was 3.67 MeV/A and 4.7×4.3 mm in FWHM, respectively, with a momentum spread of ± 3.1 %. The implantation rate was approximately 0.3 kBq/h.

For wear-loss diagnostics, the depth profile of implanted RI should be controlled and characterized accurately. The depth profile was controlled using a rotating energy degrader that had eight foils of different thicknesses. The foils were circularly placed on a wheel of diameter 14 cm rotating at 12 rpm so that they cross the RI beam path one by one. An additional degrader foil can be mounted on a beam collimator with a diameter of 10 mm placed downstream of the wheel.

To study the implantation-depth profile, we first irradiated a stack of 2-μm-thick Al foils with the RI beams, and measured the radioactivity of each foil with a Ge detector. Then we obtained the beam-energy spectra by the PSD, and calculated the range distribution of the ions in Al with the SRIM code[3]. Figure 1 shows a case of a ^{22}Na beam with a narrow momentum distribution of ± 1 % implanted to the stack after the rotating degrader with a blank and seven Al foils with thicknesses of 4.9, 7.6, 11.9, 16.9, 23.8, 27.4, and 31.7 μm. The depth profile with the stacked-foil is shown by black circles as relative intensities of the radioactivity in the foils. The horizontal and vertical error bars indicate the thickness and the statistical error for each foil. The dotted line shows the SRIM calculation of the range distribution from the energy spectrum. Below a depth of 5 μm, the corresponding energy spectrum could not be measured as it was below the detector threshold. The triangles indicate normalized fractions of the foils obtained by re-binning the range spectrum according to the stack-foil thicknesses. We multiplied a factor of 0.97 to the stopping power of the SRIM calculation for optimum agreement between the stacked-foil measurement and the calculation.

The conventional stacked-foil method is reliable because it directly measures the implanted RI, but its depth resolution is limited because assembling many thin foils as a stack is hard work. On the other hand, the energy measurement with a Si detector is simpler, but the accuracy of the implantation-depth distribution depends on the range calculation. Here, we combined the two methods with a correction factor for the SRIM calculation results and obtained a continuous implantation-depth profile.

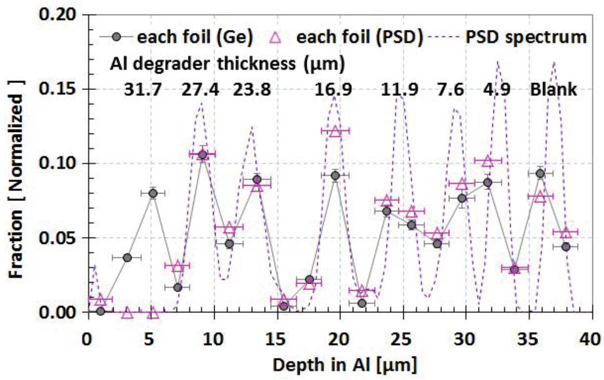

Fig. 1. Implantation-depth profile of ^{22}Na beam in stacked Al foils.

References

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