RI nuclides produced in stacked Si and Al plates by 135-MeV/nucleon ^{12}C beam

T. Kambara*[1] and A. Yoshida*[1]

On the basis of a fee-based facility sharing program, private companies in Japan use heavy-ion beams to simulate single-event effects (SEE) on space-use semiconductor devices by cosmic rays.[1] The clients have utilized ion beams of Ar, Kr, and Xe from the RIKEN Ring Cyclotron (RRC) at the E5A beam line. The primary ion beam is spread with a scatterer foil and wobbler magnets and extracted to atmosphere. Then, it passes through transmission-type detectors for dose measurements and an energy degrader for linear energy transfer (LET) adjustments. The setup and irradiation procedures were described previously.[2]

The samples irradiated by the primary beam are also impinged on by various secondary particles produced by nuclear processes in the upstream materials. To evaluate the effects of the nuclear processes, we irradiate test samples in the same beam condition as the clients' irradiation and measure RI nuclides by radiochemical analyses. Similar studies have been reported for a Kr beam[3] and a Xe beam.[4]

Since clients expressed interest in the utilization of a C beam, we studied the characteristics of a 135 MeV/nucleon ^{12}C beam. During the beamtime, we irradiated a stack of two Si plates (100-mm diameter and 0.5-mm thick) and two Al plates (3-mm thick) for radiochemical analyses. The irradiation setup is shown in Fig. 1. The primary beam passed through a 51.2-μm-thick Kapton® window into the atmosphere and then entered an ionization chamber (IC). From measurement with the IC, the number of ions was estimated to be approximately 1.08×10^{12} during 5 min of irradiation. Then, the beam passed a 3-mm-thick plastic scintillator (not used) and an energy degrader of 18.42-mm-thick Al. Its thickness was selected so that the primary ions stopped in the second Si plate.

We measured the γ rays from each sample plate with a Ge detector from 13.4 min to 39.7 days after the irradiation for the Si plates and from 23.7 min to 6.49 days for the Al plates. Using the observed γ-ray spectra, we identified 10 radionuclides from ^{7}Be to ^{34m}Cl. We extrapolated the decay curve of the radioactivity of each nuclide to the end of the irradiation to obtain the number of the nuclei identified in the sample. Then, we divided it by the number of primary ions to obtain the production probability of the nuclide. The nuclides can be produced by nuclear reactions either in the sample or in the upstream materials followed by transport to the sample.

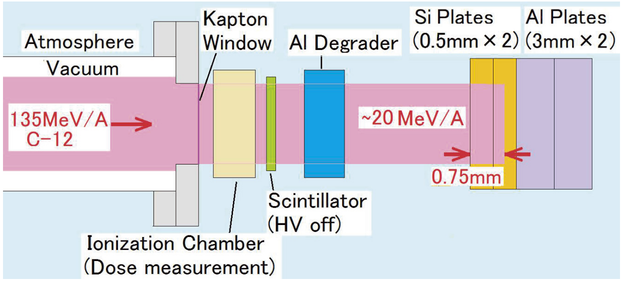

Fig. 1. Setup of the sample irradiation.

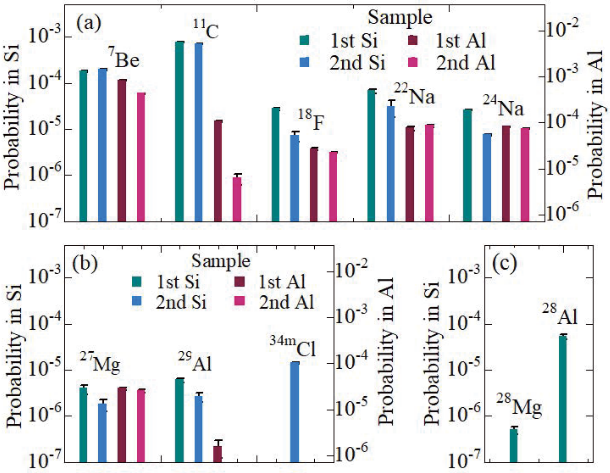

Fig. 2. Production probabilities of RI nuclides in the sample plates.

The results are shown in Fig. 2, where the colored bars indicate the probabilities in the sample plates. The values of the probabilities in the Si plates are shown on the left ordinate and those in the Al on the right so that the bar heights are scaled to the same number density of the sample atoms. Since the primary ^{12}C ions stopped in the second Si plate, the nuclides in the Al plates were either produced by secondary particles or transported from the upstream. The γ rays of ^{28}Mg and ^{28}Al shown in Fig. 2(c) were measured only in the first Si plate, and those of ^{34m}Cl in Fig. 2(b) were identified only in the second Si plate.

We are comparing the results with the simulation of nuclear processes using the Particle and Heavy Ion Transport System (PHITS) code.[5]

References

1) `http://ribf.riken.jp/sisetu-kyoyo/` (Japanese).
2) A. Yoshida, T. Kambara, RIKEN Accel. Prog. Rep. **51**, 185 (2018).
3) T. Kambara, A. Yoshida, Record of 2018 IEEE Radiation Effects Data Workshop (REDW), p. 94.
4) T. Kambara, A. Yoshida, RIKEN Accel. Prog. Rep. **52**, 158 (2019).
5) `https://phits.jaea.go.jp/index.html`.

---

[1] RIKEN Nishina Center