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Measurement of charged particle spectra emitted following muon nuclear capture in Si nuclei

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When a negative muon stops in matter, it is captured into an atomic orbit, and subsequently, it is captured by the atomic nucleus at a certain probability through the weak interaction [1]. This process is known as muon nuclear capture (μNC). In this process, most of the muon's rest energy is carried away by a muon neutrino and the remainder is used to excite the residual nucleus. This excited nucleus may emit charged particles such as protons, deuterons, and alpha particles, in addition to gamma rays and neutrons. The low-energy spectra of these emissions reflect the evaporation process from the compound nucleus formed after μNC. Conversely, the spectral shape in the high-energy region is considered to reflect the details of the pre-equilibrium process.

The study of μNC in silicon, a primary material in semiconductor devices, is particularly relevant for understanding how cosmic-ray muons can induce soft errors, which are temporary malfunctions in semiconductor devices. Charged particles emitted following μNC can generate electron-hole pairs in semiconductors, potentially flipping the data stored in memory and causing what is known as a single event upset (SEU). The risk of cosmic-ray muon-induced soft errors is considered significant, especially with the ongoing trend of die shrinkage and reduced operation voltage[2]. Thus, measuring the energy spectra of charged particles is essential for evaluating the soft error rate for advanced semiconductor devices induced by cosmic-ray muons.

We conducted measurements of the energy spectra of light charged particles emitted after μNC at the RIKEN-RAL muon facility[3]. Negative muons were irradiated and stopped in thin silicon targets. The energy of emitted charged particles was measured using telescopes comprised of silicon detectors and CsI scintillators. Particle identification for low-energy particles that do not penetrate the Si detectors was performed using the pulse shape analysis method[4], while for penetrating particles, the ΔE-E method was used.

This presentation will report on the details and results of the experiment. The obtained energy spectra will be compared with theoretical calculations.

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