Heavy-ion irradiation on a SiC-based semiconductor detector

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Modern radioactive beam facilities including RIBF focus on spectroscopic studies of unstable, exotic isotopes through nuclear reactions. Such measurements sometimes require high-intensity radioactive beams with rates exceeding 10^5 pps. Providing beams with event-by-event particle identification necessitates time-of-flight (TOF) detectors in the secondary beam separator. However, the limited radiation tolerance of existing organic-scintillator-based TOF detectors poses technical difficulties when operating at high intensities, such as significant performance degradation over time.

The use of synthetic diamond has been explored[1] as a TOF detector with outstanding radiation resistance, and it has successfully been used for multiple physics experiments at RIBF.[2,3] Despite this, their application to a broader range of measurements remains limited because of the difficulty in scaling to larger active areas and the associated high manufacturing costs.

Possible alternatives to the existing diamond-based heavy-ion counters are silicon-carbide (SiC) radiation sensors. SiC is classified as a wide-bandgap semiconductor, with the 4H polytype exhibiting a large bandgap of approximately 3.2 eV. Its radiation hardness, derived from a high threshold displacement energy, is a desirable characteristic that broadens its applications.[4,5] Detector characterization studies using highly ionizing heavy-ion beams are required to assess the feasibility of employing a SiC detector in nuclear physics experiments, especially for detecting radioactive beam particles with precision timing information.

Within the detector-development beam time framework at RIBF, we conducted a beam irradiation experiment to evaluate the detector performance by observing the transient response of ion-induced signals and characterize its timing properties. The measurement was performed at the E7B beamline using a stable beam of ^{18}O at 7 MeV/nucleon supplied from the RIKEN AVF cyclotron. A recently developed 4H-SiC detector with a pixelated pn-junction diode structure,[6] fabricated at the National Institute of Advanced Industrial Science and Technology, was used for this test. The beam was incident on the SiC detector after passing through a thin plastic scintillator, which served as a time reference. The beam intensity was adjusted to achieve a detector count rate of 10 counts per second.

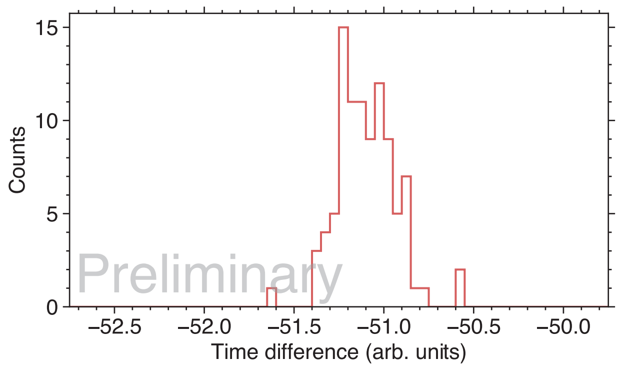

Fig. 1. Time difference measured between the plastic scintillator and the SiC detector.

The transient response of the SiC detector to ^{18}O ion implantation was successfully observed. The signals from the detector were recorded using either a digital oscilloscope or an analog-memory-based fast digitizer. Only 50 Ω termination of the signal transmission line enabled a clear observation of the signal without external amplification because of the rapid charge collection. The time difference between the scintillator and the SiC detector was extracted using a digital constant-fraction timing analysis of the captured waveform (see Fig. 1). The results show promising performance for its use as a timing detector at in-flight radioactive beam facilities.

Our ongoing efforts focus on fabricating detectors with an enlarged active area and characterizing the device after long-term continuous heavy-ion irradiation that emulates actual detector operating conditions. The results obtained in this measurement will soon be submitted for publication, where a more comprehensive description will be provided.

References
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DOI:10.34448/RIKEN.APR.58-144