Channeling effect in ultra-thin monolithic silicon telescopes

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Determining the cross section of the $^{8}\mathrm{Li}(\alpha,n)^{11}\mathrm{B}$ reaction in the low energy regime $E_{\mathrm{cm}} < 2$ MeV has been of particular interest in recent decades.[1,2)] In a potential inhomogenous Big Bang scenario, this reaction could bridge the mass gap at $A = 8$, leading to the evolution of heavier nuclei in the very early universe. Furthermore, full network calculations indicate that this reaction could play a vital role in enhancing the r-process nucleosynthesis in supernovae.[3,4)]

Multiple experiments have been performed to determine the low-energy cross section using the inverse kinematics of a ^{8}Li beam incident on a ^{4}He gas target.[2,5,6)] However, data are scarce and show remarkable discrepancy below $E_{\mathrm{cm}} < 1.7$ MeV owing to difficulties with the accurate identification of the low-energy reaction products.[2)] A new method was proposed at RIKEN to study the low-energy resonances using ultra-thin ΔE-E monolithic silicon telescopes (MSTs)[1)]. Each telescope consists of five ultra-thin $\sim$1 µm (ΔE) silicon detector pads on a $\sim$500-µm-thick (E) silicon detector. Experiments performed in 2005 show promising results for identifying the reaction at even a low energy of $E_{\mathrm{cm}} \cong 0.5$ MeV.[7)]

To assure optimal detector performance for the final cross-section measurement, it is crucial to determine the MST characteristics and response for particles incoming at different angles of incidence. Ultra-thin silicon detectors are particularly prone to the channeling effect, which degrades the detector signal for particles incident along the detector crystal planes or axis by significantly reducing the stopping power. Moreover, the exact detector characteristics remain unknown, and determining the thickness of the two dead layers in the telescope could reveal the detector threshold for particle identification.

The tandem Pelletron accelerator at the Nishina Center, RIKEN was used to accelerate 4-MeV ^{11}B, 9-MeV ^{63,65}Cu, and 7- and 25.5-MeV ^{197}Au ions into the MST. The telescope was attached to a rotation stage within the target chamber allowing accurate remote angular control with respect to the ion beam. Approximately 30000 coincidence events in the ΔE and E detector were collected at varying angles of incidence for each selected ion beam.

Our study reveals the influence of the channeling effect in the ΔE-E particle identification spectrum with respect to detector orientation (see Fig. 1). A tail extending from the 4-MeV ^{11}B main peak in the spectrum was observed at specific detector angles, and it was attributed to the channeling effect. The channeling ratio was defined as the ratio of the number of events in this tail (N_{chan}) to the number of events within the main peak (N_{peak}). By determining the channeling ratio as a function of detector angle the silicon crystal orientation could be deduced. Our results indicate that the channeling effect can be significantly reduced by orienting the silicon detector at 10° facing the anisotropic silicon crystal orientation in between the crystal axis [111] and ⟨231⟩.

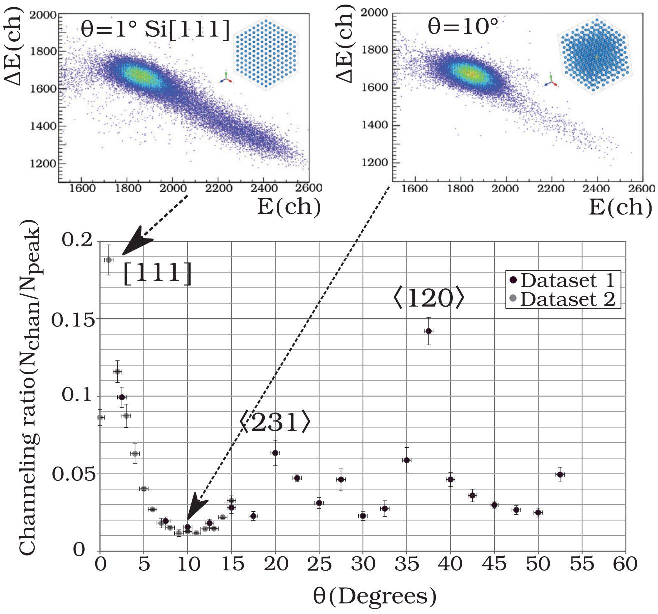

Fig. 1. Channeling ratio versus detector angle θ for 4-MeV ^{11}B. The ΔE-E particle identification spectrum is displayed for the [111] silicon crystal axis and at 10° with the minimal channeling ratio. The peaks with high channeling ratio are indicated with the corresponding silicon crystal axis.

References

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