^{26}Si beam production and thermal durability test of gas target window

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The study of the αp process is important for understanding nucleosynthesis in x-ray burst. The process, which is composed of alternating (α, p) and (p, γ) reactions, is considered the bridge between the CNO cycle and rp process. Owing to technical issues, most of the astrophysical (α, p) reactions on radioactive isotopes are less understood experimentally, including the $^{26}\mathrm{Si}(\alpha,p)^{29}\mathrm{P}$ reaction. The energy levels of ^{30}S falling in the Gamow window of the reaction at x-ray burst temperatures ($T = 1 - 3$ GK, $E_x = 10 - 14$ MeV) are crucial for the $^{26}\mathrm{Si}(\alpha,p)^{29}\mathrm{P}$ reaction rate. Many energy levels were identified through previous works,[1)] but the spins of levels above $E_x = 10$ MeV are not constrained in many cases. Additionally, no energy levels above $E_x = 12.4$ MeV have been measured so far. Thus, we thus plan to measure the $^{26}\mathrm{Si}(\alpha,\alpha)^{26}\mathrm{Si}$ elastic resonant scattering. We simultaneously expect that the $^{26}\mathrm{Si}(\alpha,p)^{29}\mathrm{P}$ reaction is also directly observable, which requires a rather high-intensity ^{26}Si beam. The primary beam intensity is, however, limited to only approximately 200 pnA to prevent the deposited heat from breaking the F0 gas target window (Havar foil). Therefore, other types of foils were tested during the beam time.

We took 1.5 days out of the approved 12 days of beamtime to test the ^{26}Si beam production at the Center for Nuclear Study Radioactive Ion Beam Separator (CRIB)[2)] of the University of Tokyo in December 2019. A primary beam of $^{24}\mathrm{Mg}^{8+}$ was accelerated by the AVF cyclotron at 7.5 MeV/nucleon and with a maximum intensity of 400 pnA, bombarding the cryogenic ^{3}He gas target of 0.94 mg/cm^2. The ^{3}He gas was confined with windows of 3-μm-thick Ti foil ($\phi = 20$ mm), which has a lower thickness and higher heat conductivity than the commonly used Havar foil, with the expectation of a higher injecting beam intensity. The beam of the radioactive isotope ^{26}Si was produced by the $^{3}\mathrm{He}(^{24}\mathrm{Mg}, ^{26}\mathrm{Si})n$ reaction. We installed a 0.2-mg/cm^2-thick carbon foil as a charge stripper to obtain a higher population of the highest charge state $^{26}\mathrm{Si}^{14+}$. The magnetic rigidity was set to 0.61208 Tm to select the desired beam energy of 5.2 MeV/nucleon. The voltage of the subsequent Wien filter was ± 85.5 kV. A ^{26}Si purity of 59% and a beam intensity of about 4.7×10^4 particles per second were achieved at the F3 focal plane, which are much higher than those of the previously produced ^{26}Si beam at CRIB.[3)] The particle identification plot at F3 is shown in Fig. 1. This improvement may be attributed to the higher primary beam intensity, the thinner gas target window foil, the newly installed charge stripper, and the higher Wien filter voltage.

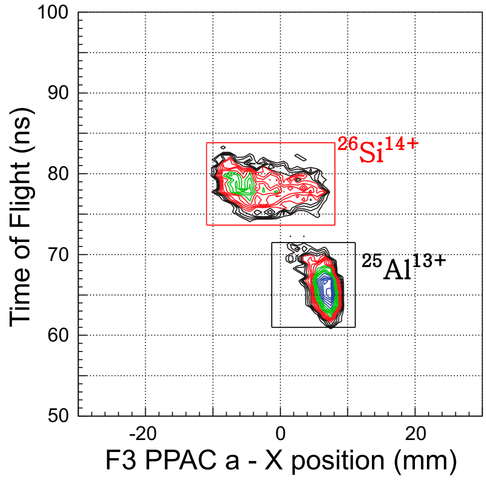

Fig. 1. Particle identification spectrum obtained at the F3 focal plane. The ^{26}Si beam is clearly separated from other beam particles.

We also investigated the thermal durability of other materials of the gas target window through primary beam injection. We installed Mo (100% molybdenum, thickness: 3 μm, thermal conductivity: 138 W/m/K, melting point: 2896 K), Ti (100% titanium, thickness: 3 μm, thermal conductivity: 21.9 W/m/K, melting point: 1941 K), Havar (thickness: 2.5 μm, thermal conductivity: 13 W/m/K, melting point: 1753 K) and CuBe (98% copper, 2% beryllium, thickness: 3 μm, thermal conductivity: 105 W/m/K, melting point: 1143 K) foils held by copper frames on a rotating wheel[4)] in the F0 chamber. The temperature of each window was monitored by thermography. The foils were exposed to a $^{24}\mathrm{Mg}^{8+}$ primary beam up to an intensity of about 2800 enA, at which all the foils were pin-holed on the beam-spot position but the Mo foil endured. The typical beam size is measured to be about 2 mm. We also tested those foils mounted on the gas-filled target cell with liquid-nitrogen cooling-except the CuBe foil. We exposed the Ti foil to a 2600 enA $^{24}\mathrm{Mg}^{8+}$ beam and the Havar and Mo foils to 1800 enA beams. The result shows that only the Mo foil resisted breakage, suggesting that it is the most durable material. This is consistent with the highest thermal conductivity and melting point among the tested materials. We will determine the upper limit of the heat deposition rate through further investigation. We anticipate that a higher intensity of the secondary ^{26}Si beam could be realized when Mo foils are used at the F0 gas cell.

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