Development of a gas target for the spectroscopy of pionic atoms in inverse kinematic reactions

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We are preparing for the spectroscopy of deeply bound pionic atoms to study the density dependence of chiral condensate. Thus far, pionic atom spectroscopy has been performed with the $(d, ^3\mathrm{He})$ reaction at RIBF.[1] We plan to perform spectroscopy using inverse-kinematics reaction to achieve higher excitation-energy resolution than the current best resolution of 287 keV.[1] Since the momentum spread of the incident beam does not contribute to the resolution in this inverse kinematics, we aim at an unprecedented resolution of ∼150 keV.

The deuterium gas target requires thin vacuum windows because the thickness directly contributes to the resolution of the excitation-energy measurement for achieving the intended resolution. The thickness is required to be smaller than 400 μg/cm^2. Furthermore, the windows are required to withstand the irradiation of high-intensity heavy-ion beams under a pressure difference of ∼1 bar.

As candidates for vacuum windows, we consider two types of windows of 1 μm thickness made of graphenic carbon (GC) and silicon nitride (SiN), which corresponds to ∼ 400 μg/cm^2. They have been used as vacuum windows for X-ray and electron beams.[2–4] Further, in our previous test in 2019, the GC windows of 1 μm were tested with ^{20}Ne beams without any pressure difference, and they withstood 200 particle nA beams for up to 10 hours.[5] However, these windows have not been tested with high-intensity heavy-ion beams under a pressure difference.

We tested the windows under pressure differences of 0.5 and 1 bar with a $^{20}\mathrm{Ne}^{8+}$ beam of 8.2 MeV per nucleon and up to 40 particle nA provided by AVF. The criterion for the performance of the windows is withstanding an integrated current of 9×10^3 particle nA·min. This corresponds to 24 hours of irradiation with a Xe beam at 2 particle nA in the inverse kinematics experiment in terms of total energy deposition.

Figure 1 shows the experimental setup. The beam was first collimated by a slit with a diameter of 3 mm and passed through two beryllium windows that isolated the beam-line vacuum section from our setup. Then, the beam was incident on the window sample

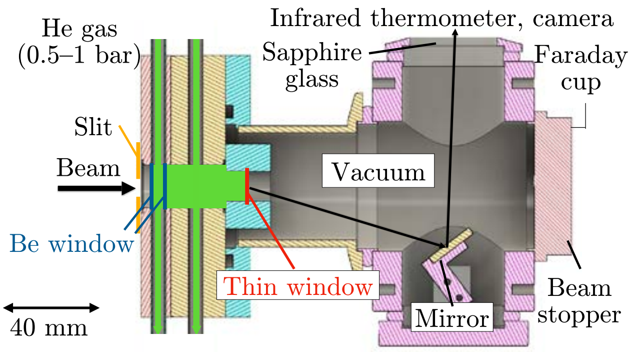

Fig. 1. Experimental setup.

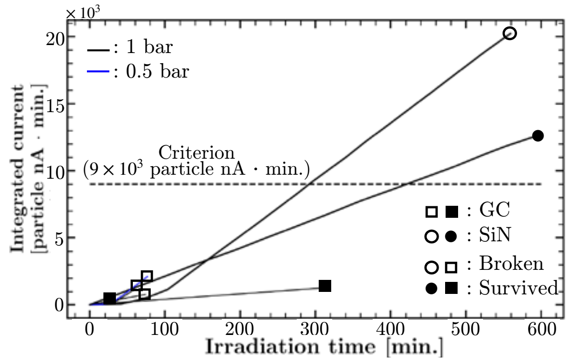

Fig. 2. Current and irradiation time. The symbols show the status of the foils after the irradiation.

with an energy of 5.9 MeV per nucleon and stopped at a Faraday cup. The temperature of the window was monitored using an infrared thermometer.

Figure 2 shows the results of the test experiment. The GC windows were tested under pressure differences of 0.5–1 bar, and they were broken after the integrated current reached 1000–2000 particle nA·min. The SiN window withstood an irradiation of 2×10^4 particle nA·min under a pressure difference of 1 bar. During the irradiation, the temperature of all tested windows remained below the lower limit of the infrared thermometer (150°C).

In conclusion, the SiN windows demonstrated an order of magnitude better performance than that of the GC windows in terms of the integrated current. The SiN windows achieved the criterion for the inverse-kinematics experiment, 9×10^3 particle nA·min, with a safety factor of ∼ 2. We plan to further conduct ex-

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periments focusing on SiN windows for finalizing the design of the gas target to be used in the pionic atom spectroscopy experiment.

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