Development of $^{178\mathrm{m}2}$Hf isomer target

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Since the discovery of superdeformation in the nucleus, many superdeformed states have been observed [1]. As the further deformed state, hyperdeformation, in which the ratio of the long axis to the short axis is 3 : 1, has been predicted as extreme quadrupole deformation[2]. However, no such state had been discovered yet. Furthermore, recent theoretical calculation predicts that even a deformed torus shape appears at a high-spin state[3]. Such deformed states will provide us with a stringent test of our understanding of nuclear physics. The key to produce such states is transferring high angular momentum to the nucleus. If the high-spin target or beam is available, it would be more probable to populate such an exotic state. Thus, we are developing a target of $^{178\mathrm{m}2}$Hf, [a] which has a high spin of $16\hbar$ and a long half-life of 31 y. Among several reactions, the ^{176}Yb$(\alpha, 2n)$ reaction is known to have a relatively high cross section to produce $^{178\mathrm{m}2}$Hf[4]. The pioneering work to produce 3×10^{14} atoms of $^{178\mathrm{m}2}$Hf was performed in Dubna[5]. The isomeric state was produced by the fusion reaction of $(\alpha, 2n)$ with an enriched ^{176}Yb target. At an incident energy of 35.5 MeV, the cross section was 9 mb and the isomer ratio was 0.5 %. The AVF cyclotron at RIBF can provide 40-MeV α beams of 10 eμA, which are enough to make a nanogram sample of $^{178\mathrm{m}2}$Hf with a beam time of a few days. Before stepping into mass production, we performed the feasibility study for production. There are three issues to be checked. The first issue is the measurement of the excitation function of the production cross section of $^{178\mathrm{m}2}$Hf to optimize the incident beam energy. The second issue is the production cross sections of ^{175,172}Hf, which will be the main contaminants after the irradiation. Since they have relatively short half-lives, 70 d and 1.87 y, respectively, the radioactivities of these contaminants will be much larger than that of $^{178\mathrm{m}2}$Hf if we use a natural Yb target. The production cross sections of these nuclei determine the degree of enrichment required for ^{176}Yb. The third issue is the heat damage to the Yb target. It is not obvious that the target can withstand the high-intensity α beam since the melting point of Yb is about 824 °C.

The experiment was performed at the C03 beam line of the AVF cyclotron. An α beam of 40 MeV irradiated a target stack for 8 hours. The target stack was made of ten $^{\mathrm{nat}}$Yb foils with a thickness of 20 μm each. The Yb foils were sandwiched by two 2-μm Ti foils to check the energy of the beam using the monitor reaction $^{\mathrm{nat}}$Ti$(\alpha, xn)^{51}$Cr. The target was placed on the water-cooled Ta Faraday cup to measure the total dose of the beam. In addition, He gas was flown on the surface of the target to take the heat away. The irradiation time was determined by the regulation for production of ^{175}Hf in this facility.

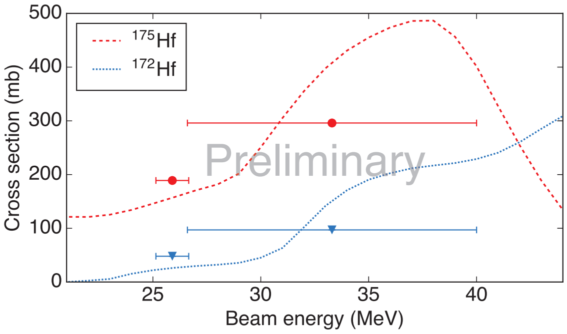

Fig. 1. Experimental cross sections for $^{\mathrm{nat}}$Yb$(\alpha, xn)^{175}$Hf (circles) and ^{172}Hf (triangles) are compared with the calculations by PACE4 (dashed and dotted, respectively). The horizontal errorbars stand for the loss of energy in the foils.

When we opened the chamber and checked the target after cooling for 3 days, it turned out that the first ten foils, one Ti and nine Yb, were adhered. On the other hand, the last two foils, Yb and Ti, could be separated. This means that as long as the foils are attached tightly to the water-cooled Faraday cup, they can withstand the 10-eμA α beams. γ rays were measured by a HPGe detector to evaluate the radioactivities produced. The deduced cross section of ^{51}Cr was found to be consistent with the value with an incident energy of 40 MeV. The cross sections of $^{\mathrm{nat}}$Yb$(\alpha, xn)^{175,172}$Hf are presented in Fig. 1. The PACE4 code[7] reproduced these experimental values. For detecting the decay from $^{178\mathrm{m}2}$Hf, we have to measure γ rays in triple coincidence to distinguish them from other activities. We are now preparing Ge detectors array GRAPE[8] for the measurement.

References

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[a] There are two isomeric states in ^{178}Hf. One is $^{178\mathrm{m}1}$Hf with a half-life of 8.0 s, the other is $^{178\mathrm{m}2}$Hf.