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Improvement of thickness and uniformity of isotopically enriched ^{12}C targets on backings by the HIVIPP method

I. Sugai[a,*], Y. Takeda[a], H. Kawakami[a], Y. Nagai[b], N. Ohta[c]

[a] *High Energy Accelerator Research Organization, Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan*
[b] *Research Center for Nuclear Physics, Osaka University, Mihogaoka 11-1, Ibaraki, Osaka 567-0047, Japan*
[c] *Advanced Research and Development Division, Toyo Tanso Co. Ltd., 550-0011, Takeshima, 5-7-12, Nishiyodogawa-ku, Oosaka-shi, Japan*

Abstract

We have made enriched ^{12}C targets to accurately measure the cross-section of the $^{12}C(\alpha,\gamma)^{16}O$ reaction, which is very important in nuclear astrophysics. Isotopically enriched ^{12}C targets for studying this small cross-section, especially for use with an intense pulsed α beam was desired to meet the following requirements: (1) use of impurity-free enriched ^{12}C, (2) stability for a long time measurement and (3) uniform thickness in the range 200–300 μg/cm^2. To meet these experimental requirements, isotopically enriched amorphous ^{12}C powder was converted into graphite powder in an electric furnace at a temperature of 3000 K and subsequently the graphite powder was deposited on a thick Au backing via the HIVIPP method. Targets thus prepared could be made thicker than 200 μg/cm^2. They had a good uniformity and a very high stability against irradiation with high intensity ion beams.

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Keywords: Carbon; Carbon disk targets

1. Introduction

The $^{12}C(\alpha,\gamma)^{16}O$ reaction is a key reaction of nuclear astrophysics [1–3], and its reaction rate determines the relative amounts of ^{12}C and ^{16}O produced by red-giant stars and their subsequent evolution. Hence the precise value of the reaction cross-section is crucial to construct models of stellar evolution. Although the cross-section is extremely small at the astrophysical relevant energy E_α(c.m)$\leqslant$1.5 MeV, experimental efforts have been made to determine the cross-section accurately. However, there is a large discrepancy of about a factor of 4 between different data sets [4]. This discrepancy is mainly considered to result from the ^{13}C impurity of the target, the poor uniformity of the target thickness and the variation of the thickness during the measurement.

For this experiment, we, at first, prepared isotopically enriched, self-supported ^{12}C foils of 200–300 μg/cm^2, using the thermal cracking method. However, these foils had short lifetimes when bombarded with high intensity ion beams as shown in Fig. 1(a) and (b). The short lifetimes were presumed to be due to the poor heat conductivity of the foils, because no backings were used. This short lifetime did not allow effective data taking, because the foils had to be replaced frequently. To overcome this issue, we prepared isotopically enriched ^{12}C targets on Au backings by means of the *HI*gh energy *VI*brational *P*owder *P*lating (HIVIPP) method [5–7]. The HIVIPP method works at room temperature and results in a strong adhesion to the substrate. However, the maximum accessible thickness of the targets was limited to about 80 ± 10 μg/cm^2 and the thickness uniformity was quite poor because the charged powder to be deposited was accumulated almost along the ring corner (often >95%) as shown in Figs. 6(a) and 7 of Ref. [8]. We have processed the ^{12}C powder varying the diameter of the glass ring, the substrate material, and the applied DC and AC high voltages. However, every attempt showed the same unexpected results. On the other hand, when we used commercial available ^{nat}C powder, the

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[*] Corresponding author. Tel./fax: +81 298 64 5576.
E-mail address: isao.sugai@kek.jp (I. Sugai).

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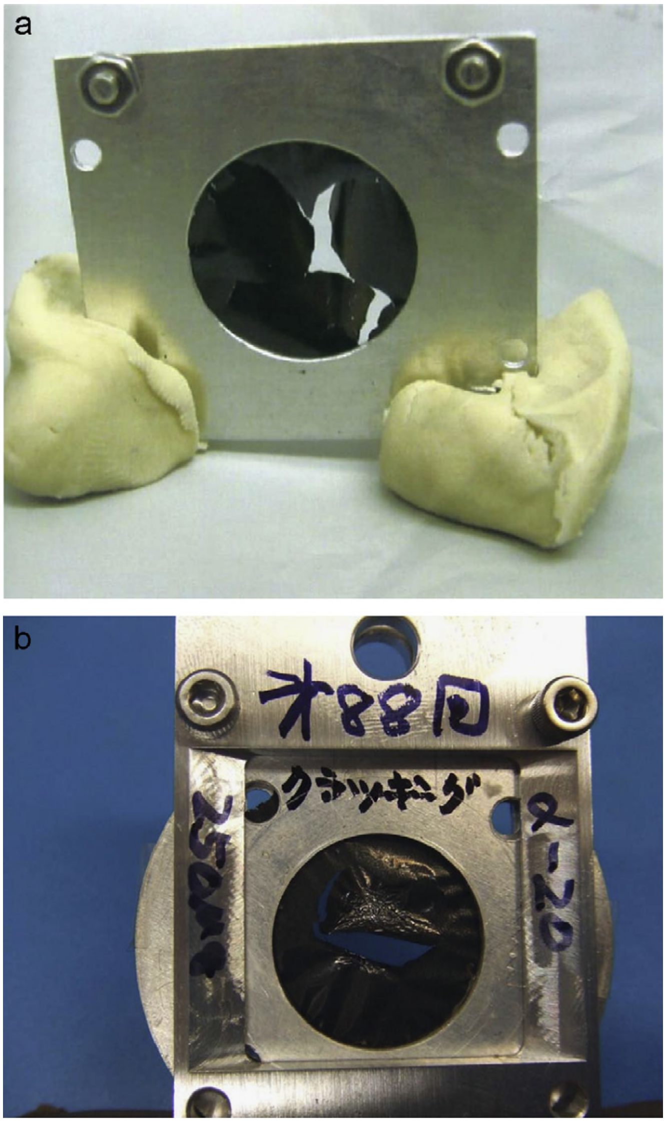

Fig. 1. (a) Photograph of a ruptured ^{12}C target of 272 μg/cm^2 made by thermal cracking from CH_4 gas. The foil was irradiated with a 2.2 MeV He^+ ion beam of 6 μA on a spot of 5 mm diameter. The lifetime of the foil was 6 h. (b) Photograph of a ruptured ^{12}C target of 310 μg/cm^2 made by thermal cracking from CH_4 gas. The foil was irradiated for only 30 min with a 3.2 MeV Ne^+ ion beam of 2.5 μA on a spot of 3.5 mm diameter.

deposit did not accumulate along the ring corner as shown in Fig. 6(b) of Ref. [8]. The difference between (a) and (b) was considered to be due to the primary difference of the crystalline size between the amorphous ^{12}C powder and natural graphite powder. Hence, we used both powder made by thermal cracking from $^{12}CH_4$ at approximately 1500 K, and, on the other hand, powder produced by electron beam heating of amorphous ^{12}C flakes in vacuum at 2100 K for 6 h. However, no improvement was observed. Next, we graphitized the amorphous ^{12}C powder in a high temperature electric furnace. Using thus produced crystalline ^{12}C powder, we have successfully prepared uniform carbon targets thicker than 250 μg/cm^2. The same procedure was successfully applied to amorphous ^{13}C powder. We have compared the crystal size of the graphitized ^{12}C to the natural graphite powder by the X-ray diffraction (XRD) method. We have also measured the adhesion to the gold backing by using a 3.2 MeV Ne^+ ion beam.

2. Target preparation

The isotopically enriched ^{12}C material was available as amorphous powder compacted to flakes. About 780 mg of ^{12}C powder were placed in two high purity carbon crucibles and pressed down with a carbon lid. The two crucibles (60 mm diameter and 90 mm long) were inserted in an Acheson type of graphitization furnace, as shown schematically in Fig. 2. Purging nitrogen gas through the furnace, the crucibles were heated for 3 h at approximately 3000 and 3500 K, respectively. We also treated the 511 mg of amorphous ^{13}C powder in the same way. These crucibles were heated at 3200 K for 3 h in nitrogen gas.

The samples were removed from the furnace after cooling down to room temperature and were weighed subsequently. The weight reduction was 5% of the initial weight.

Since the particle size of the graphitized powder was too big to use the HIVIPP method, the powder was ground to make a fine powder (about 100 μm) using a fresh agate mortar, and the powder was heated in vacuum at about 1300 K for 7 h in a Ta filament chimney crucible to remove impurities in the materials.

The apparatus of the HIVIPP method was almost the same as shown in Fig. 1 in Ref. [8]. It is very simple and it consists of two parallel backing disks 0.2 mm thick and

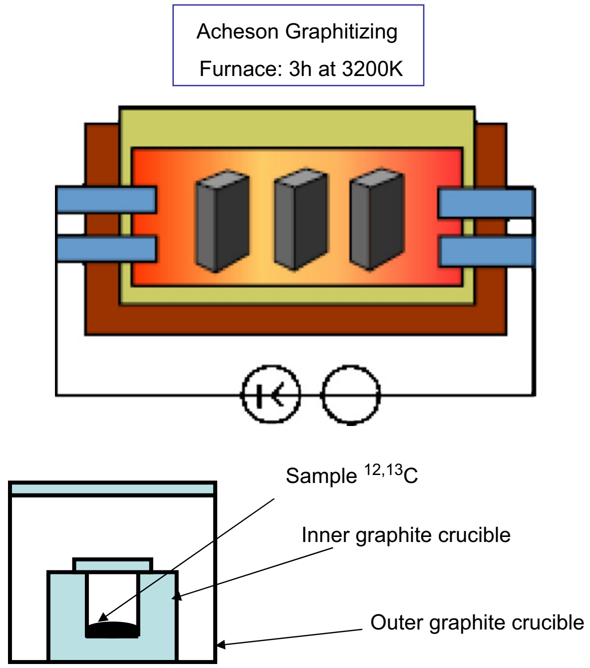

Fig. 2. Schematic drawing of the Acheson graphitization furnace.