DEVELOPMENT OF A TARGET SYSTEM FOR RARE ISOTOPE BEAM PRODUCTION WITH HIGH-POWER HEAVY-ION BEAMS*

J.S. Song, S.K. Hong, J.H. Kim, M.J. Kim, J.W. Kim#, Rare Isotope Science Project (RISP), Institute for Basic Science (IBS), Daejeon, Korea

Abstract

We are designing a graphite target system for the maximum primary beam power of 400 kW for the rare isotope science project in Korea. The main design ion is U beam at the energy of 200 MeV/u in the beam current of roughly 8 pμA. The power density reaches above 50 MW/cm^3 inside the target with the thickness of approximately 2 mm. To enhance radiation cooling, the graphite target is thought to have multiple layer structure. Thermo-mechanical analysis has been performed using PHITS and ANSYS for both single and multi-slice targets. Empirical tests were made using electron beams for single-slice graphite target with the thickness of 0.2 mm. The power density reached around 30 MW/cm^3 and the hot spot temperature was around 900 °C, which was measured by using IR cameras.

INTRODUCTION

In-flight fragmentation method utilizing a heavy-ion primary beam and a thin target will be employed to produce various isotope beams for rare isotope science project (RISP) [1]. The existing nuclear science facilities worldwide currently provide the maximum beam power of a few tens of kW, while the next generation facility is planned to use a few hundred kW of primary beam.

The maximum beam power for the RISP is designed to be 400 kW, and the target for the secondary-beam production must be able to sustain very large power density especially for U beam at the energy of 200 MeV/u, which is the main design ion in the target design. A beam size of 1 mm is assumed on the target to attain the momentum resolution needed to separate the isotope beam of interest.

The high-power target for in-flight fragmentation has been numerically studied using PHITS [2], which is a heavy-ion radiation transport code to evaluate the generation of heat and radiation. The target thickness near optimum for the production of ^{132}Sn isotope beam is around 1.7 mm, which corresponds to 30 % of the U beam range in the energy of 200 MeV/u, and the energy loss along the target is estimated about 86 kW as shown in Fig. 1. The resultant power density inside the target reaches above 50 MeV/cm^3, and radiation cooling is critical.

Test of thermal properties of a thin graphite disk target having high power density is carried out using an electron beam up to the energy of 50 keV. The graphite thickness of 0.2 mm was determined by considering the mechanical strength as well of radiation cooling. The maximum hot-spot temperature is considered to be less than 2000 °C. This single slice target test was aimed to study thermo-mechanical properties of a rotating graphite disk. The radiation cooling of the multi-layer target has been analysed with ANSYS [3], and we plan to test multi-layer target using an electron beam of higher energy in the future.

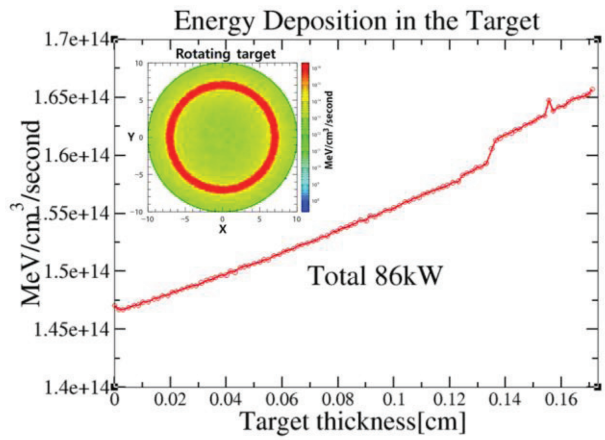

Figure 1: Beam energy deposit estimated by PHITS calculation for a graphite target of 1.73 mm thick.

DESIGN OF ROTATING TARGET SYSTEM

The graphite disk for e-beam test has the diameter of 13 cm, which is limited by the vacuum chamber size of the electron beam device, and is rotated by a motor located outside of the chamber. The graphite disk of 0.2 mm thick is attached to the shaft in the axis by aluminium frame as shown in Fig. 2. The schematic diagram of ferromagnetic seal system for vacuum feed-through of rotating shaft is also indicated. The rotating speed is variable up to 5000 rpm to study the effect on maximum temperature as heats are deposited by electron beams.

The design of aluminium frame to fix thin graphite target is an important issue in view of reducing the stress when the target is heated by the beam. When the temperature increases, radiation cooling becomes more dominant compared to conduction cooling. However, we are considering water cooling along the shaft.

In the current design, the water cooling line is sealed using vacuum o-rings, and later it will be redesigned to use more radiation hard material.

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# jwkim@ibs.re.kr

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In the electron beam experiment, test was carried without water cooling system turned on as it can interfere with an e-beam accelerator system. We used instead gas-cooling connected to the water line. However, the test was disrupted by vacuum breakage due to melting of the o-ring, which suggested water cooling could be of help in reducing the maximum temperature of the target. Also, it was found that the graphite disk was torn in the early stage of the e-beam irradiation. A new design, which is thicker in the region grabbed to the aluminium frame, is being considered, will be tested soon.

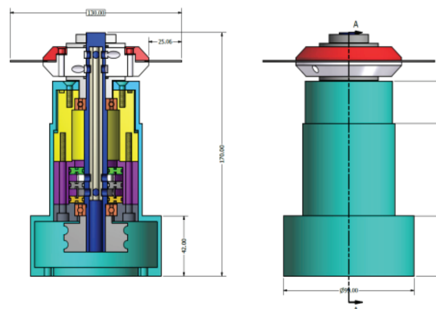

Figure 2: Design views of the single-slice target system for an electron beam test, which employs a ferromagnetic seal for vacuum feed-through of rotating shaft.

HOT SPOT TEMPERATURE CALCULATION AND MEASUREMENT

The thermo mechanical analysis to calculate the temperature and stress distributions for the target have been performed using ANSYS. Currently the effect of target rotation is not dynamically considered. The simulation results were compared to experimental outcomes in search of the optimal design of the target system.

Figure 3 shows the electron beam irradiation system in the local company, EB tech Inc., where we performed electron beam tests. The electron beam generated from a tungsten filament at the top of the chamber vertically irradiates the target located in the chamber. The electron beam is focused to the diameter of approximately 2mm by a solenoid lens. The electron beam up to the energy of 50 keV was used with the beam current in the range of 3-20 mA.

Two different IR cameras, Flir [4] and Chino [5] were used. The Flir camera produce 2D image updated every second, and the spot location of temperature measurement by Chino camera is indicated by a laser point.

Temperature Dependent on Different Dimensions of Single Slice Target

Temperature distributions of single slice graphite disk were calculated for its different dimensions assuming the U beam diameter of 2 mm in Gaussian shape. For two different diameters of 13 and 30 mm, hot spot temperatures are shown in Fig. 4 as a function of electron beam power. Also shown are the temperatures of two different thicknesses of 0.2 and 1 mm.

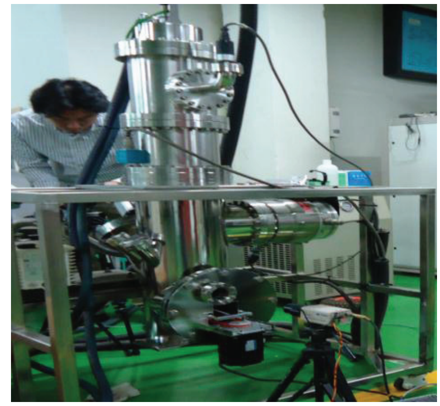

Figure 3: Photo of the electron irradiation system at the local company, EB Tech Inc. The vacuum during measurement was kept around ~10^{-6} mbar. Temperature on the graphite target was measured through glass windows using two kinds of IR thermometers.

These results are the basis of the selection of the target thickness and the minimum diameter required to limit the temperature below 2000 ^{o}C.

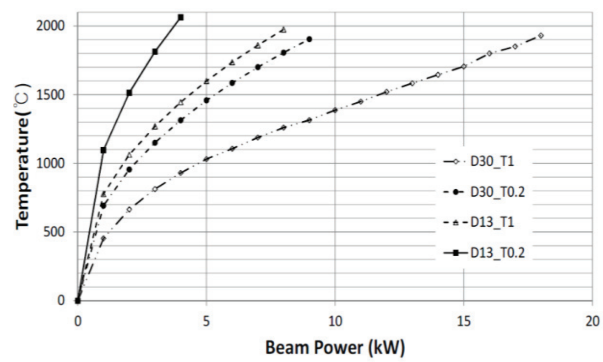

Figure 4: Temperatures of a graphite disk for two different diameters of 13 and 30 and for two different thicknesses of 0.2 and 1 mm calculated as a function of the beam power.

Thermal Analysis for a Single and Multi-Slices

ANSYS have been used to study temperature increase for single and multi-slice targets including radiation cooling assuming the emissivity of 0.85 in the case of electron beam heating. Figure 5 shows the effect of the temperature reduction by using a multi-slice configuration. The target temperature with 10 slices reaches at 1900 ^{o}C with the beam power of around 90 kW, while the single slice can sustain roughly 20 kW.

Hot Spot Temperature Dependent Upon Rotation Speed

The thermal behaviour of rotating target irradiated by an electron beam is plotted for rotating speeds from 1000 to 5000 rpm assuming the diameter of 30 cm as shown in Fig. 6, which was simulated with LISE++ [6]. Temperature fluctuation is less at the high rotation speed. Limiting this temperature variation is critical for our beam condition as the steady state temperature is already around 2000 °C. The temperature fluctuation of 200 °C can result in greatly shorter lifetime of the graphite target due to much higher evaporation rate.

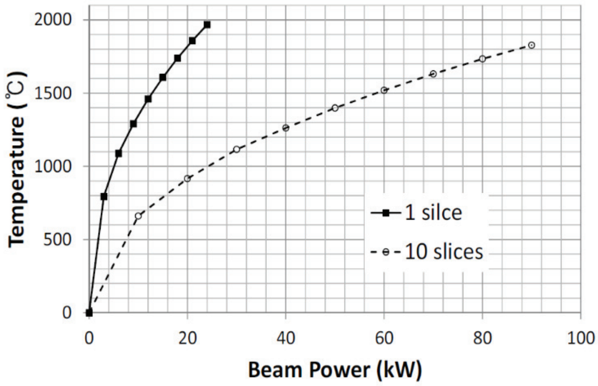

Figure 5: Comparison of surface temperatures for single and multi-slice targets.

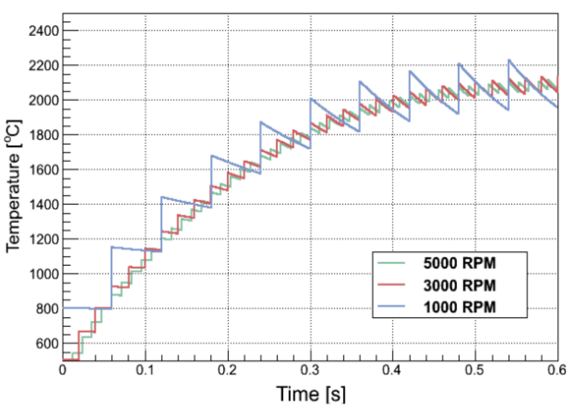

Figure 6: Temperature variation versus initial time of rotation of a graphite target bombarded by an electron beam. The lines with different colours correspond to different speeds. Equilibrium temperature is reached less than 1s.

Comparison of Measurement with Calculation

The graphite target was irradiated up to 50 keV of electron beams, which have the penetration depth estimated as 40 um by CASINO [7]. Figure 7 summarizes the results of calculation and electron beam measurements. Especially the measured temperature at 800 rpm shows a good agreement with the simulation result by ANSYS.

The fact that shows the high temperature at low rotation velocity is indicated the rotating method can be used the same way to heat dissipation effectively as the beam rotation at a stationary target.

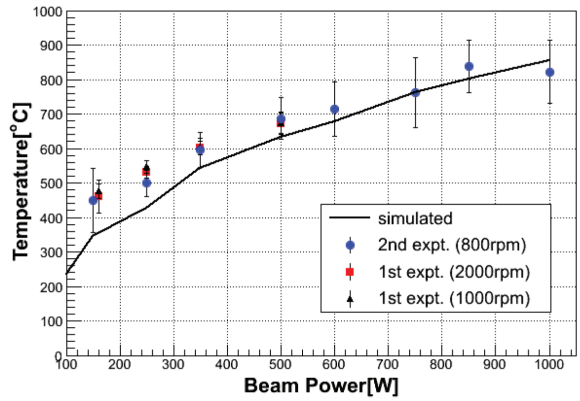

Figure 7: Comparison of measured temperature to the simulation results using ANSYS. Error bars indicate one standard deviation of the measured value.

Thermal stress, which led to tearing of the graphite disk, is still not fully understood. ANSYS analysis showed that the stress due to finite-depth penetration of the electron beam is not significant, but this ANSYS result is applicable in steady state. The unsymmetrical heating may cause higher shear stress, and there is still a possibility that thermal shock due to finite penetration of heat wave can damage the thin disk.

CONCLUSIONS

A thin rotating graphite disk has been studied for in-flight fragmentation target using the primary beam power of 400 kW. Thin target is needed to effectively dissipate the heat by radiation. A single-slice graphite was tested using electron beam up to the energy of 50 keV, and the power density inside the target reached around 30 MW/cm^3. A crack in the target due to thermal stress will be further studied. A tapered target with the thickness of around 1 mm at the location of the aluminium frame is being considered to enforce mechanical strength of the target. On the other hand, multi-slice graphite disks, which can dissipate up to around 100 kW, have been studied using ANSYS. We plan to test a multi-slice target using electron beam at much higher energy.

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