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DEVELOPMENT OF TARGET/ION SOURCE FOR LI-8 BEAM AT KOMAC*

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Abstract

A target/ion source (TIS) for Li-8 isotope beam has been developed at Korea Multi-purpose Accelerator Complex (KOMAC). The TIS was designed based on various numerical studies such as Monte Carlo simulation for Li-8 yield estimation, an ionization efficiency calculation of a surface ionization ion source and thermal analysis by a power balance model. Then, it was fabricated that a prototype of the TIS which consists of a beryllium oxide (BeO) target, a graphite target container, a tantalum target heater and a rhenium surface ion source. Also, the target heater and the surface ion source were heated to designed operation temperatures. In addition, it has been designed and constructed that an online test facility including Li-8 beam optics and diagnostics.

INTRODUCTION

The KOMAC plans development programs to improve proton linac performance and to supply various particle beam such as Li-8. Li-8 is useful isotope utilized in a beta-detected nuclear magnetic resonance (β-NMR) technique [1]. However, the β-NMR facility at Isotope Separator and Accelerator (ISAC) in TRIUMF is only available one [2]. Thus many β-NMR facilities are planned, designed or constructed in worldwide [3-5]. Also, the KOMAC has developed the Li-8 beam system based on 100 MeV proton linac for the β-NMR experiment. Fundamental design concepts are the beryllium-based target material, the surface ionization ion source, and compact beam optics. Based on these main design concept, the various numerical studies were carried out to specify design parameters of the TIS and a beam line. The prototype of TIS was manufactured and tested. The detail description about results of the numerical studies and the experiments will be described.

NUMERICAL STUDY TO DESIGN TIS

The numerical study was conducted to deduce the specific design of the TIS. FLUKA [6] was applied to assess Li-8 production rate of the BeO target and determine the target design. The simple particle collision model was developed to estimate the ionization efficiency of the surface ionization ion source (SIS). In addition, a temperature of the target heater and its heating current were calculated by the zero-dimensional power balance model.

FLUKA Simulation

In order to simulate a nuclear reaction in the BeO target irradiated by the 100 MeV proton beam and find the optimum target design, the FLUKA code was utilized. The lithium and the neutron production rates were calculated for different BeO thicknesses. The Li-8 generation increases and saturates according to the target thickness because $^{9}Be(p, 2p)^{8}Li$ reaction has a threshold energy near 20 MeV. In contrast, the neutron production rate increases steadily, as shown in Fig 1. Thus, the target thickness was determined about 24 mm which produces enough Li-8 and prevents unnecessary neutron production. The Li-8 production rate at this thickness is approximately 10^{10} particles by 1 μA of the 100 MeV proton beam.

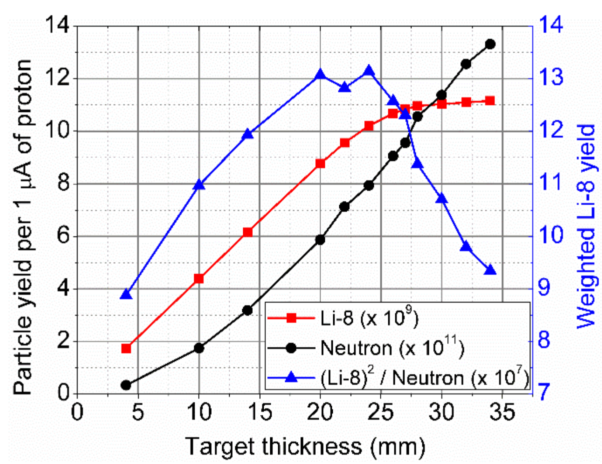

Figure 1: Li-8 and neutron production rates according to BeO thickness.

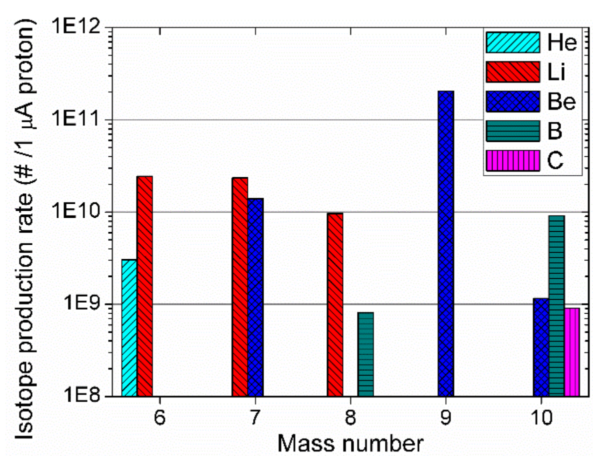

Figure 2: Isotope production rates of the BeO target irradiated by 1 μA of 100 MeV proton beam.

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Also, FLUKA estimated the production rates of other nuclides. Especially, the lithium and the beryllium nuclides are generated more than Li-8, as depicted in Fig. 2.

The beryllium should be eliminated to make a purified Li-8 beam. Thus, the surface ion source will be utilized in the TIS. The SIS is very efficient for the ionization of the alkali metal such as the lithium. Thus the lithium can be ionized selectively in the TIS.

Estimation of Ionization Efficiency of SIS

The simple particle collision model was developed to assess the surface ionization efficiency of the various species produced in the BeO target. This model considered a surface ionization defined by the Langmuir-Saha equation, an ion confinement effect by a potential structure inside SIS and a Lambertian collision [7-9]. A geometry of SIS is assumed as a cylinder with 3 mm inner diameter. Detail description of the model can be found elsewhere [10].

According to the model results, the SIS design parameters were determined. The SIS material is a rhenium and the length of the SIS should be longer than 30 mm. An operating temperature of SIS should be higher than 1800ºC. The ionization efficiency of the lithium was expected about 70% with these design parameters. On the other hand, the ionization efficiency of the beryllium was practically zero.

Power Balance Model for Thermal Analysis of TIS

In order to ionize the Li-8 generated inside the BeO target, the Li-8 should diffuse outside the target and be evaporated at the target surface and effuse into the ion source. Additionally, these processes had better spend a short time as possible, because the half-life of the Li-8 is 0.84 sec. Generally, these processes are accelerated by the temperature. Thus, key parts of the TIS should be operated at higher temperature. Also, there are some operating temperature limits. The temperature of the BeO target must be higher than 1340ºC, the boiling point of the lithium. Meanwhile, a higher limit of the operation temperature is determined by a dissociation of BeO. The BeO, which is heated to 1800ºC and placed in vacuum pressure lower than 0.01 Pa (7.5×10^{-5} Torr), is dissociated into the beryllium and the oxygen gas [11]. Thus the higher limit of the operation temperature of the BeO target depends on the vacuum pressure of the TIS. The higher limits of the other parts are determined by their melting points. In order to deduce the operation temperature and an electrical current for Joule heating, zero-dimensional power balance model was developed. In this model, the target heater was considered as a tantalum resistor determined by the structure and the resistance depending on the temperature. The heat was transferred from the heater sequentially to the graphite container, the BeO target, the container ends and ambient by the radiation. There is no consideration of a geometry effect or spatial distribution. According to this rough estimation, there was 100 ~ 200 ºC difference between the target heater and BeO target temperatures. Thus, the design parameters of the target heater were 1500 ~ 1800 ºC with 1300 amperes heating current.

TARGET HEATER AND SURFACE ION SOURCE HEATING EXPERIMENT

The prototype of the TIS was manufactured for an offline test. For the test, 1600 amperes can be supplied to heat the target heater and 400 amperes can be supplied to heat the SIS. The respective heating currents and biased net voltages of the heater and SIS were recorded. The temperatures were measured by a pyrometer through a viewport located side of the TIS. An effect of a boro-silicate glass viewport on the temperature measurement was less than 5%. Fig. 3 is a photo pictured through the viewport when the target heater and the ion source were heated. The temperatures of the heater and the SIS for various heating currents are depicted in Fig. 4.

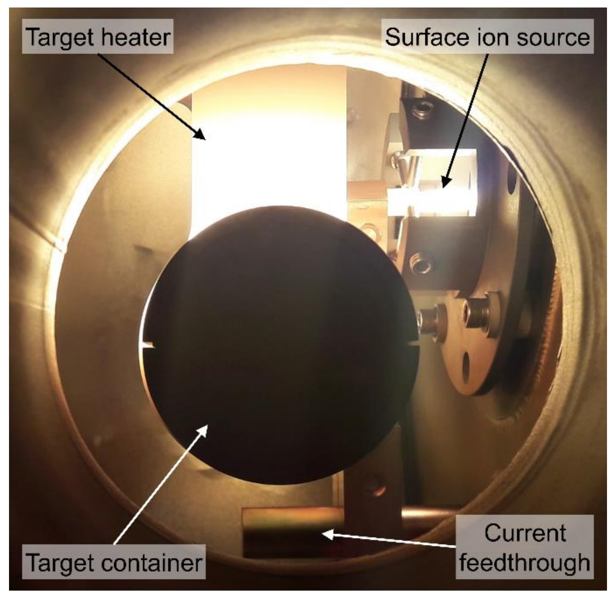

Figure 3: Inside the TIS heated by 1300 A heater current and 400 A ion source heating current.

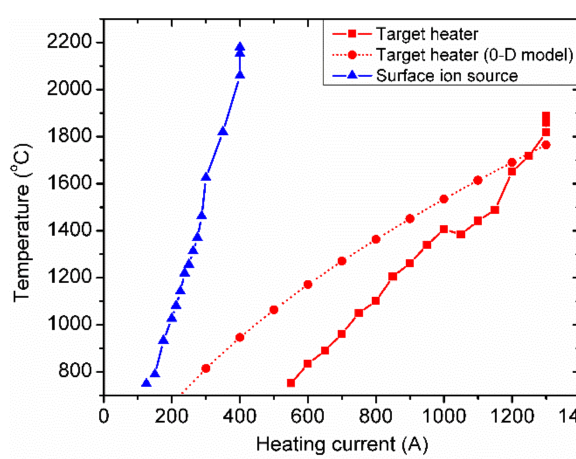

Figure 4: Temperatures of the target heater and the SIS for various heating currents.

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The maximum temperature recorded at the maximum current of the target heater and the SIS are 1850 °C and 2150 °C, respectively. That is, the goal temperature of each component was achieved. However, there is a difference between the 0-D model and the measurement of the target heater temperature at the lower current. One of the error sources is an emissivity of the tantalum. The emissivity of the Ta is a function of the temperature. However, the emissivity set the pyrometer was assumed as 0.2 at the all temperature range. In this case, the temperature can be underestimated at the lower temperature.

The vacuum pressure was normally sustained lower than 0.001 Pa (7.4×10^{-6} Torr) as depicted in Fig. 5. The low vacuum pressure is favorable for the Li-8 beam purity and the optics. However, the low pressure can cause the BeO dissociation. Thus, the vacuum pressure and BeO temperature should be care dependently.

In addition, the heater and SIS were heated by the maximum operation currents during 1 hour. The TIS was operated stably and the vacuum pressure was improved continuously.

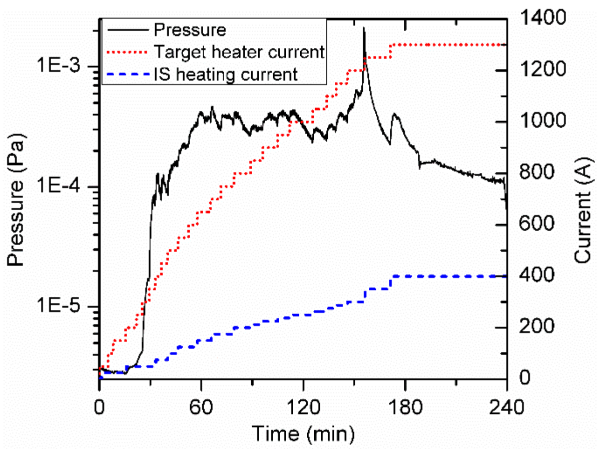

Figure 5: Vacuum pressure status for the target heater and the surface ion source heating current

CONCLUSION

The target/ion source for Li-8 beam generation have been developed at KOMAC. The TIS was designed according to the various numerical studies such as the Monte Carlo simulation and the thermal analysis. The target material is BeO and its estimated Li-8 production rate is 10^{10} particles by 1 µA of the 100 MeV proton beam. To secure the ionization efficiency of the lithium and the selective ionization, the surface ion source was adopted. For the higher ionization degree, the material of SIS is the rhenium and the operation temperature is over than 1800 °C. The operation temperature of the tantalum target heater, which heats the BeO target by the radiation heat transfer, was designed 1500 ~ 1800 °C with 1300 amperes heating current with the considerations on the Li-8 recovery, the target durability, and thermal analysis.

The prototype of the TIS was manufactured and heated according to the thermal analysis results. The measured temperatures of the target heater and the ion source met the designed values. Also, the TIS was stably operated for 1 hour with the maximum power condition. The TIS will be equipped with the beam optics components and be tested online at the 100 MeV proton accelerator of the KOMAC.

ACKNOWLEDGEMENT

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