Measurement of Double-differential Cross Section of Fragments on C, Al, Cu, Ag Induced by 400 MeV Helium

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An experimental setup is prepared for fragment spectroscopy and mass yield study in intermediate energy region. For fragment spectroscopy, fragment mass and Z number are identified simultaneously by time-of-flight and ΔE-E method using a counter telescope. Digital storage oscilloscope with segment transfer mode is used for determination of time-of-flight and pulse height from fast timing signals. Fragments from 400 MeV helium induced reaction on Al, Cu and Ag samples with 10 μm thickness are measured using this counter. The double differential cross sections from Lithium isotopes to Carbon isotopes from these samples at 30 degree laboratory angle are obtained with clear separation except for low energy region.

1. Introduction

A particle with energy ranging from several tens of MeV to a few GeV (intermediate energy) produces a fragment (products heavier than helium) through nuclear reaction. Energy and angular distribution of fragments still cannot be reproduced well because a theoretical model and its parameters are not specified. The fragment makes a considerable contribution in irradiation effects since it has large damage in a medium through energy deposit in a relatively short range. For example, to evaluate dose by intermediate energy neutron, production rate and energy distribution of reaction products, especially fragment, are indispensable. Evaluation of damage on devices, single event effect, is in same situation. Fragment production data are also important to estimate induced activity of materials around an accelerator, the power of which growth up in recent years. To evaluate not only a reaction model and its parameters but also an irradiation effect, experimental data set are important. The experiments of fragment production in this energy range divide broadly into two methods, a direct measurement and an activation method. The former can provide energy and angular distribution of fragment, the later high precise production cross section and mass yield data. To combine results by these two methods, the results of the direct measurement should be obtained separately about mass and Z since limited number of fragments can be measured by an activation method.

Experimental data of fragment energy and angular distribution with mass and Z separation are scarce except for data of 480 MeV p + Ag [1]. As a result, there are a few calculation codes which can deal fragment production. To evaluate the theoretical model implemented in such codes, the experimental data for various incident particles, energies and target nuclides are useful. In addition, a reaction mechanism of fragment production will be obvious through this evaluation process. Recently, PISA project is started to gather fragment production data from 200 MeV to GeV proton induced reaction [2].

In this study, we designed an experimental setup for fragment spectroscopy and mass yield study in intermediate energy region. For spectroscopy, a ΔE-E TOF telescope with flight path is used to obtain fragment spectra with mass and Z separation. Detail of the telescope and first results of fragment spectra

are described in following sections.

2. Experimental

Experiments have carried out at HIMAC, NIRS. Figure 1 shows experimental arrangement. Incident particle is He 400 MeV (100 MeV/u). The intensity of helium beam is 1.2×10^{10}[pps]. The beam passes through 100 μm thick aluminum exit window, 1 cm thick air and a 100 μm thick aluminum incident window to enter a scattering chamber which equips a sample changer, an activation sample holder, Farady-cup and a detector telescope. The sample changer can mount 5 different samples with 16 mmϕ, a ZnS viewer (EJ-440 by Eljen technology) and an α source (Am-241, 3.3 MBq). After pass through the sample, the incident helium beam enters to activation samples held the activation sample holder. The holder is placed at the entrance of Farady-cup which consists of a 1 m depth - 35 mmϕ internal diameter stainless steel tube and an 80 mm thick graphite column. Samples are graphite 100 μm thick for checking the detector, and Al, Cu and Ag 10μm thick. Beam profile at both samples, the center of the chamber and the entrance position of the Farady-cup, are confirmed to be less than 5 mm in diameter by using ZnS and polypropylene viewer. Fragments emitted from the sample mounted on the center enter the detector telescope at 30 degree with respect to the incident beam.

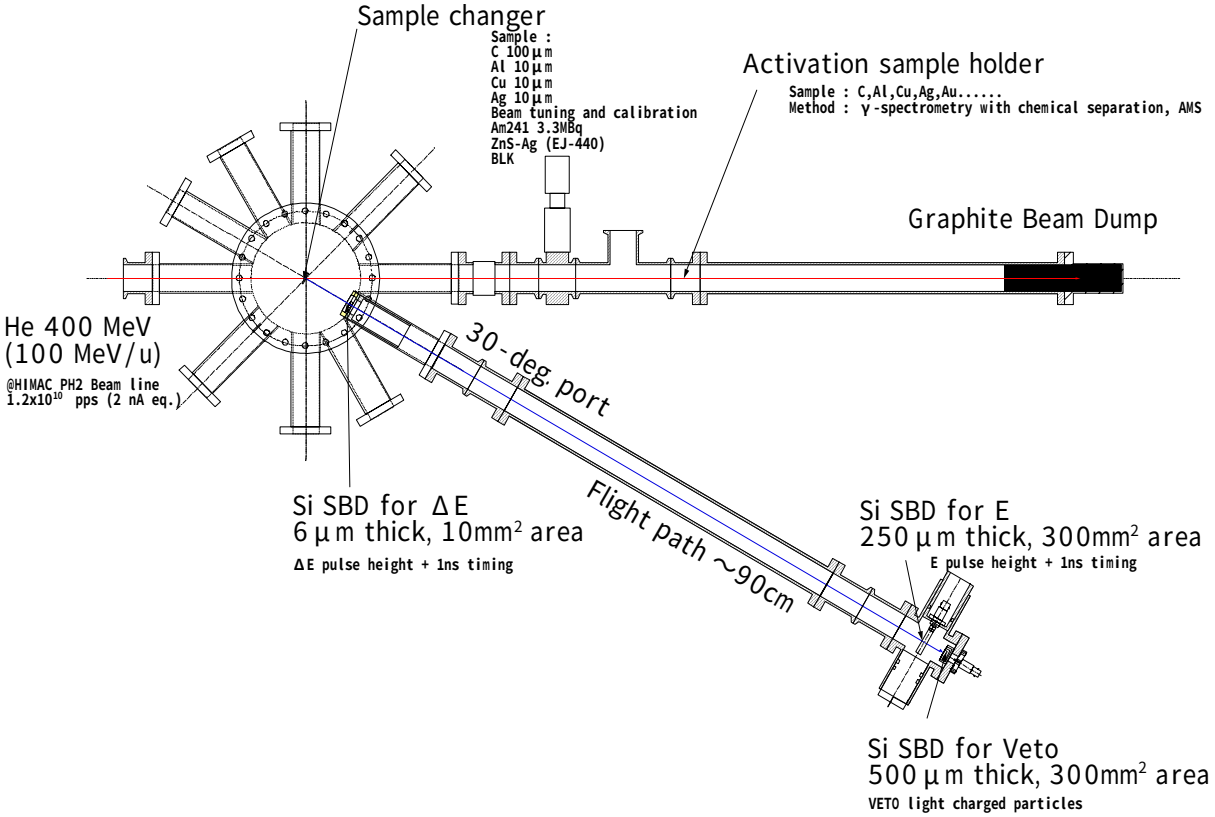

Fig. 1 Experimental arrangement for fragment spectroscopy.

The telescope consisted of three silicon surface barrier detectors (SBDs) of 6 μm, 250 μm and 250 μm thick used as ΔE, E and Veto, respectively. The SBD for ΔE is placed at 7 cm from the sample, which is important to maximize detector efficiency because an active area of the thin SBD is small (10 mm^2). The SBD for E is placed at the 90 cm position from the ΔE. The active area of the SBD is 300 mm2. The SBD for Veto is placed just behind the one for E. The distance is determined with considering mass

resolution. The solid angle of this telescope is determined by counting α particles placed at the sample changer. By this array, mass and Z number of a fragment can be identified by ΔE-E and Time-of-flight method, simultaneously. As a ΔE detector, a thin-film scintillator combined with double photo-multiplier readout also tested. An energy resolution of the combination is not sufficient to identify z-number however a timing resolution sufficient.

The outputs from the SBDs are fed to a fast-preamplifiers after pass through Bias-tees. The fast-preamplifier provides an output pulse, rise time of which is less than 5 ns, typically. A digital storage oscilloscope (DSO) is connected with the outputs of the pre-amplifiers to record the waveforms from each SBDs, because the signal is too fast to analyze pulse height using a conventional amplifier module. Trigger signal for DSO is generated from output signal of the pre-amplifier using a constant fraction discriminator to pickup events with a low pulse height. To enhance data accumulation rate, the DSO is operated with a segment recording mode. The data are sent to PC through Ethernet when its memory filled up. Typical dead time rate is 0.6~0.8 which is corrected using the ratio of real triggers to accumulated events. Owing to close position of ΔE counter, only 2 hours are needed to obtain following results for each samples. It is important because the period is enough as irradiation time of the activation sample. Products of the activation sample are determined using γ-spectrometry with chemical separation and AMS. Details of the procedures are described at other paper [3].

3. Data Analysis

From the waveform data, pulse height and arrival time are determined for each events. Pulse height is obtained from integration of the pulse. Arrival time is determined as the time when the signal reaches 20 % of the peak value. These values are booked as column-wise-ntuple data for PAW event by event. Coincidence analysis and particle identification are performed using PAW. Figures 2 and 3 show scatter plots of ΔE-E and E-TOF, respectively. As shown in these figures, separation of Z and mass number is clear except for low energy particles. The relationship between energy and pulse height is determined using deposit energy of punch through particle at E SBD. Using the relationship between mass, energy and time-of-flight, a mass-E scatter plot is made as shown in figure 4. Energy loss corrections in ΔE detector and the sample are performed using range-energy curves obtained from SRIM code [4]. Normalization factors are determined by normalizing about beam current, number of sample atoms and solid angle.

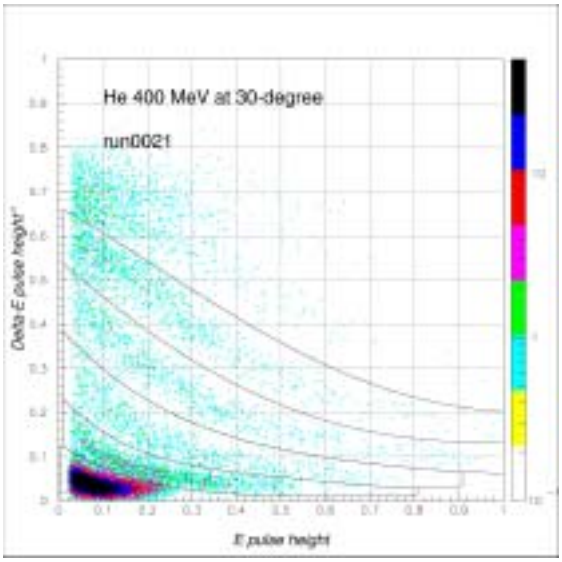

Fig. 2 ΔE-E spectrum for Al sample.

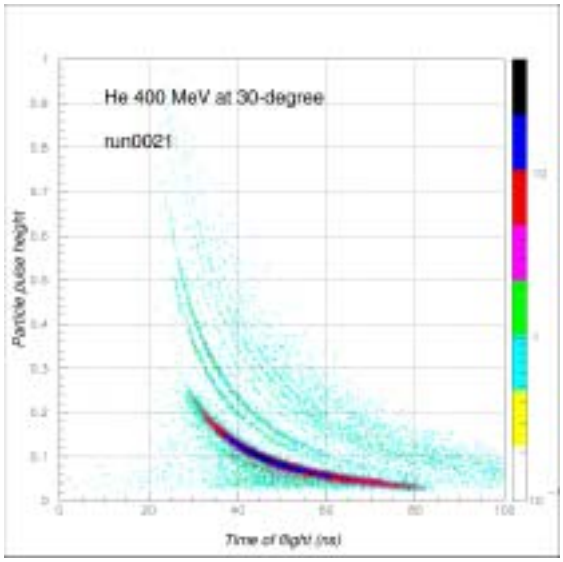

Fig. 3 E-TOF spectrum for Al sample.

4. Result

Figure 5 shows results of double differential cross sections for isotopes of Lithium, Beryllium, Boron and Carbon for each samples at 30 degree on laboratory frame. Upper energies of these spectrum are limited from the thickness of SBD. For Lithium, the energy corresponds to ≅60 MeV. In these figures, there are still problems since Z and mass resolution are not enough to identify fragments below ≅20 MeV. For example, there are a few ^{8}Be events which should not be observed owing to its short life. As shown in figure 4, these events are originated by timing walk. The almost all spectra will be still affected by the walk at low energy. Since the ΔE-E separation is also not enough in low E region, this method should be improved with focusing on the measurement of low energy fragments.

From fig 5, statistics of main products are in fairy sufficiency such as Lithium 6,7, Belilium 7,9,

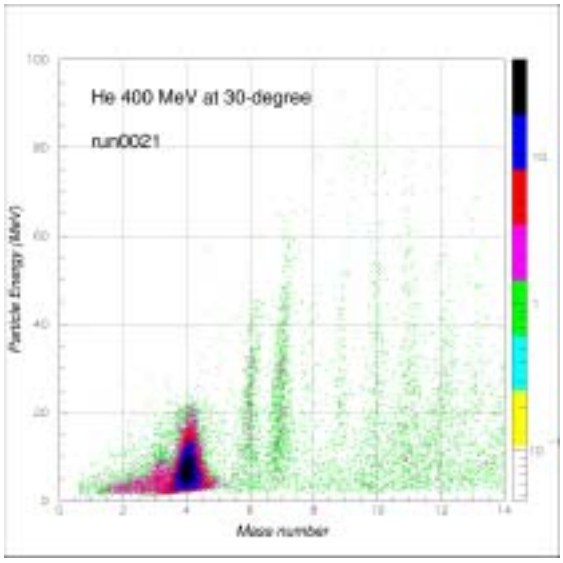

Fig. 4 Mass-E spectrum for Al sample.

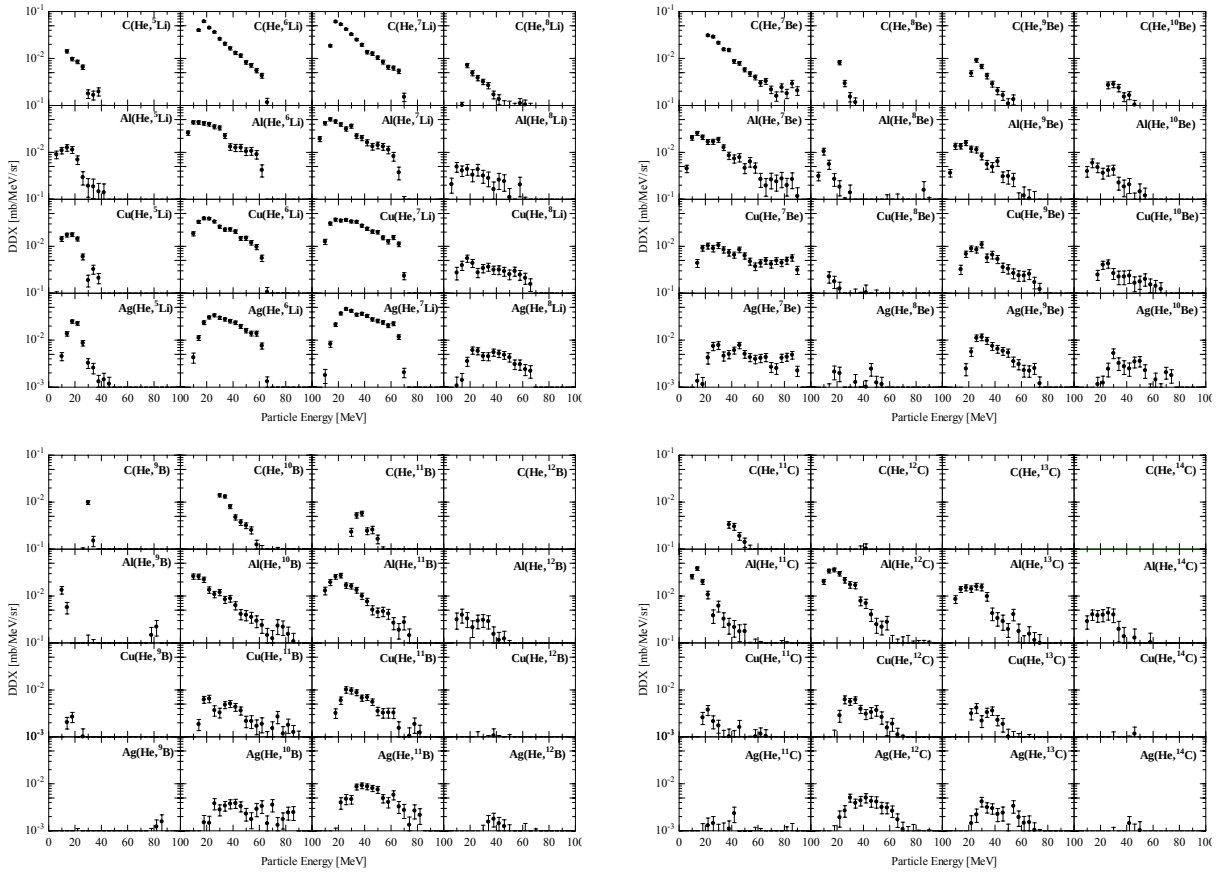

Fig. 5, Fragment production cross section at 30-degree for C, Al, Cu, Ag sample.

Boron 10,11 and Carbon 12,13, however counting time and beam current are not so much. For these fragments, target dependencies in energy spectrum are roughly observed. Thresholds of the system are too high to observe evaporation peak because of relatively high energy losses in the target for the Cu and Ag case. The target thickness can be reduced to half ot its thickness since it will be compensated by dead time reduction using a high speed DSO.

5. Conclusion

In the present work, a counter telescope which can determine fragment mass and Z number by using time-of-flight and ΔE-E method is prepared for an experimental setup which enables fragment spectroscopy and mass yield study, simultaneously, in intermediate energy. By using this setup, fragment spectra with mass and Z number separation are obtained for C, Al, Cu and Ag samples with only two hour measurement with 1.2×10^{10} pps incident helium beam. The mass and Z resolution of the spectra are not sufficient in low energy region. Nevertheless, target dependencies in energy spectrum are observed for isotopes of Lithium, Beryllium, Boron and Carbon. These results have led to next experiments; incident energy and angular dependence are intended with the improvement of the low energy fragment measurement.

References

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