Improvement of charge resolution for intermediate energy heavy ion using CR-39 plastic nuclear track detector

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Abstract. **It is essential for the study of galactic cosmic ray origin to measure precise cross section of projectile fragmentation for heavy ion on hydrogen and helium target at intermediate energy between a few hundred and a few thousand MeV/nucleon in laboratory system. As charge identification determines the measurement precision of cross section, an improvement of charge resolution for heavy ions with intermediate energy using CR-39 PNTD has been made. We showed that a limitation of Z was about 20 for the identification of nuclear charge Z with enough charge resolution < 0.15 charge units (cu) in rms) under optimized etching time, depending on the projectile energy. However, the charge resolution of the CR-39 PNTD is found to be drastically improved by averaging the measurement data of multiple layers of the CR-39. This improvement leads us an excellent charge resolution better than 0.15 cu. for a wide range of elements as for projectile. These results will support us to measure the fragmentation cross sections precisely using CR-39 PNTD.**

Keywords: **CR-39, Fragmentation cross section, charge resolution**

I. INTRODUCTION

It is essential for the study of galactic cosmic ray origin to measure projectile fragmentation cross section for heavy ion on targets such as hydrogen, helium and carbon at intermediate energy[1]. Many experimental and theoretical works on the heavy ion fragmentation reaction have been carried out so far from the interests of not only cosmic ray astrophysics but also other fields such as radiobiology, space dosimetry, and radiation shielding[2][3][4]. However, there remain considerably inconsistent results between experiments and models. Therefore, we aim to perform the precise and accurate measurements of the fragmentation cross section systematically for intermediate energy heavy ions from C up to ultra heavy nuclei (Z > 26) on some ISM targets using CR-39 plastic nuclear track detectors (PNTDs). The CR-39 PNTD has excellent advantages in position sensitivity and charge resolution in comparison with active spectrometers such as scintillation counter, Si detector, and Cherenkov counter mostly used in the previous works. These advantages provide us rich information on heavy ion fragmentation, e.g., reaction point in target material determined with a few micron accuracy, emission angle of fragments, branching ratios of variously produced fragments in multi-fragment events such as C→3α, and so on. The information enables us to measure more precise and detailed cross sections rather than the previous measurements. Because of these backgrounds, we have developed the new measurement system for the projectile fragmentation cross section using the CR-39 PNTD[5][6].

Charge resolution for heavy ions with intermediate energy using CR-39 PNTD was improved as a part of a series of the development of our measurement system. The uncertainty in the charge identification largely is attributed from the error of measured cross section. Therefore, we aimed to achieve the charge resolution of 0.15 cu for all elements of projectile with intermediate energy.

II. EXPERIMENT

Stacks composed of a sheet of CR-39 PNTD and a carbon target placed in front of the CR-39 PNTD were set up in the beam experiment as shown in Fig. 1. The sizes of the CR-39 PNTD and target were 5 × 5 cm^2, and their thicknesses were about 0.9 mm and 2 - 4 cm. The thickness of carbon target was adjusted for each run, and it is enough for projectile with Z to produce about several percents fragments with Z-1. After chemical etching, it becomes possible to specify the Z of incident ion from the size of opening mouth of etch pit (etch pit area) because the size of etch pit area depends on energy loss of the ion in the CR-39 PNTD. Two kinds of the CR-39 PNTDs, Harzlas TD-1 and BARYOTRAK (manufactured by Fukuvi Chemical Industry) were used. The TD-1 has a good charge resolution for a wide range of projectile elements with Z greater than three at the intermediate energy. Meanwhile, the BARYOTRAK is insensitive to particles with lower Z than about 13, but it can be expected to have the better charge resolution for particles with the higher Z, compared to the TD-1 from the calibration data [7]. Therefore, it is capable to identify a wide range of elements with Z > 3 up to ultra-heavy nuclei by a combination of both detectors with better charge resolution.

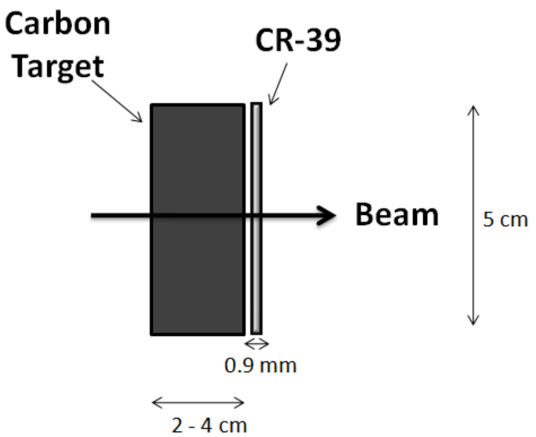

Fig. 1: Schematic drawing of experimental stack

Each stack was exposed to C, O, Si, Ar, Fe, Kr, and Xe beams with the energies of 0.1, 0.2, 0.3, 0.4, 0.5 and 1 GeV/n, respectively at Heavy Ion Medical Accelerator in Chiba (HIMAC) in National Institute of Radiological Sciences and Alternating Giant Synchrotron in Brookhaven National Laboratory. The exposed density for each run was about 1000 ions/cm^2. After the exposure, the stacks were decomposed, then the CR-39 PNTDs were etched in seven normal NaOH solution at 70 degrees C for 5, 10, 15, 20, 25, 30, 40, 50, 60, 75, 90, and 105 hours, step by step. For each beam run, about 5 × 1 cm^2 in the center of the CR-39 PNTD was analyzed at each etching time using the HSP-1000 (at × 20 objective lens and with incident light) and Pit Fit, then the charge resolution between the projectile with Z and the fragments with Z-1 was investigated.

III. RESULTS

First, we optimized etching time in the etchant of seven normal NaOH solution at 70 degrees C. Because the study of etchant was fully reported so far by many investigators, NaOH solution has been conventionally used. Therefore, the improvement of the charge resolution was mainly studied by optimizing the etching time. Fig. 2 (a) and (b) show correlations between the etching time and charge resolutions for C, O, Si, and Ar at the energies of about 300 MeV/n in TD-1 and ones for Ar and Fe in BARYOTRAK, respectively. The results of Kr and Xe are not shown in the figure because those ions were not identified at all. It is obvious that the charge resolution is rapidly improved as the etching time increases in common with all elements of beams in both detectors. However, the improvement slows down from about 30 hours (h), and then the charge resolutions become constant. For this reason, we regarded 30 h as optimum etching time.

In practical use, the less etching time is better when the charge resolution keeps constant. The beam density is largely limited as the etching time increases because the enlarged etch pits are easier to overlap each other. Overlapped etch pits prominently make it difficult to be automatically recognized. Thus there is no advantage of enlarging etch pit ex-

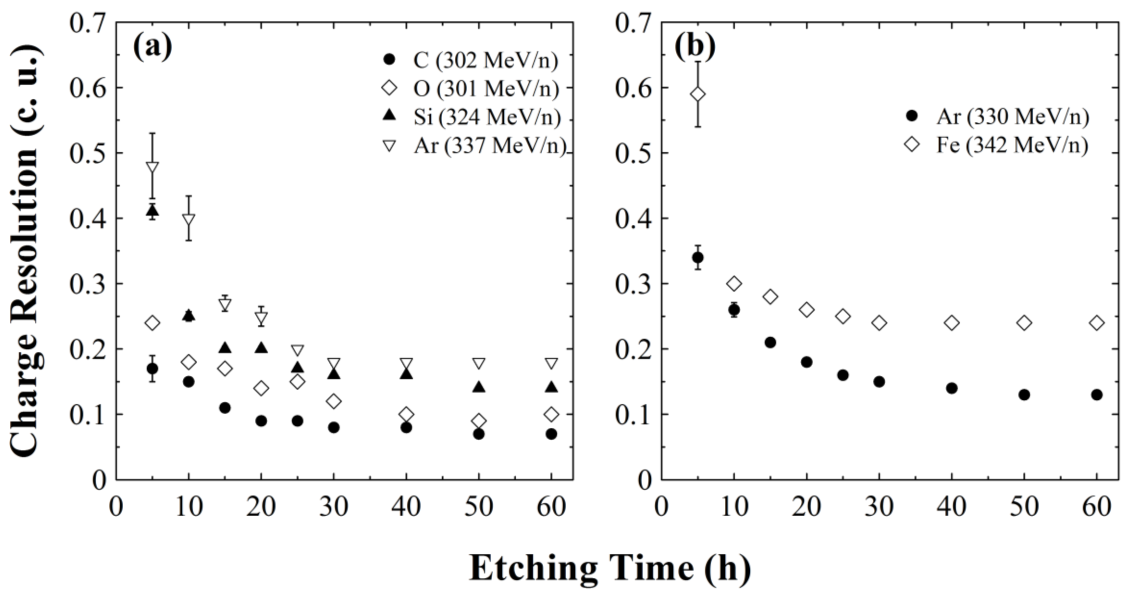

Figure 2 (a). Correlations between the etching time and charge resolution in TD-1 (a), and BARYOTRAK (b).

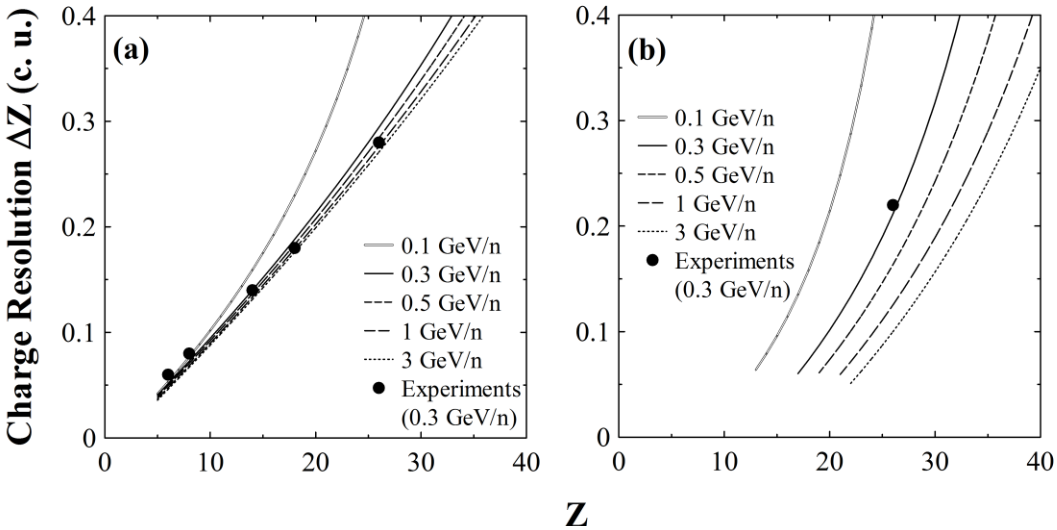

Fig. 3. Estimated and measured charge resolution for various projectiles at 0.1, 0.3. 0.5, 1 and 3 GeV/n in (a) TD-1. (b) BARYOTRAK.

cept for the improvement of charge resolution. Therefore, the 30 hours, when the improvement of charge resolution stops, is regarded as the optimum etching time.

Finally, we succeeded in making empirical estimation of the charge resolution for both of the TD-1 and BATYOTRAK. The procedure to make the estimation will be shown in the following paper [9] in more detail. Those preliminary results are shown in Fig. 3. It was found that limitations of Z to be identified with enough charge resolution (< 0.15 charge units (c. u.) in rms) are approximately Z = 15 and 20, depending on the projectile energy. Therefore, further improvement of the charge resolution is essential to identify the heavier ion than Fe.

IV. DISCUSSION

The simplest way to improve the charge resolution is to average the measured data through multiple layers of the CR-39 PNTDs by statistical effects. It is considered that the charge resolution gets better by a factor of square root of the number of averaged layers of the CR-39 PNTDs. In this section, we made some attempts to study the optimum stack designing to obtain the charge resolution better than 0.15 cu. For this purpose, we prepared the successive eight sheets of the CR-39 PNTD (BARYOTRAK) to be exposed to Fe at the energies of 350 MeV/n. By reconstruction of the trajectories, it is possible to obtain the variation of charge resolution with increase of the number of averaged layers (N). The result was shown in the Fig. 4. It is evident that the charge resolution is improved by a factor of N. Fig. 5 shows the charge distribution obtained by average of 8 layers.

By using average method, it became possible to make the optimum stack design. This method applied for the measurement of cross section is appeared in another paper in the same issue.

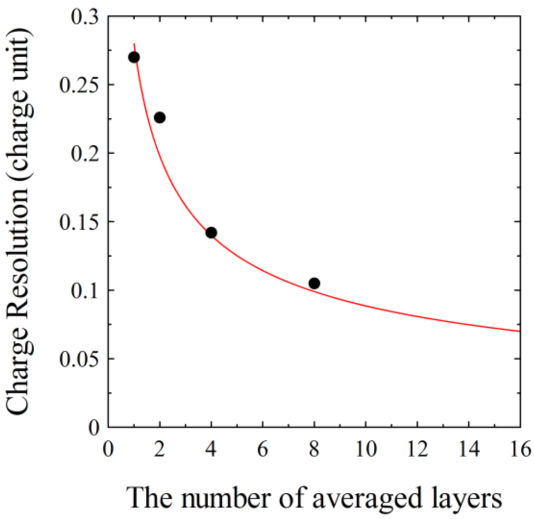

Fig. 4: Improvement of charge resolution by averaging the etch pit areas of tracks on multiple layers

V. CONCLUSION

We showed that a limitation of Z to be identified with enough charge resolution (< 0.15 charge units (c. u.) in rms) under our conventional analysis condition is Z= 20, slightly depending on the projectile energy. It was found that the charge resolution of the CR-39 PNTD is drastically improved to be better than 0.15 c. u., using averaging method. These results support us to make optimum stack and measure the fragmentation cross sections precisely using CR-39 PNTD.

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REFERENCES

[1] M. M. Shapiro and R. Silberberg, Ann. Rev. Nucl. Part. Sci., vol. 20, 323-392, (1970)

[2] G. D. Westfall et al., Phys. Rev. C 19, 1309, (1979)

[3] W. R. Webber et al., Phys. Rev. C 41, 520, (1990)

[4] C. Zeitlin et al., Phys. Rev. C 56, 388, (1997)

[5] N. Yasuda et al., Radiat. Meas., 40, 384, (2006)

[6] S. Ota et al., Radiat. Meas., 43, S195, (2008)

[7] N. Yasuda et al., Radiat. Meas. 43 S269 (2008).