High Energy Physics and Nuclear Physics

Volume 20, Number 1

A Two-Dimensional Position Sensitive Multi-Stage Detection System with a Wide Dynamic Range for Heavy Ion Reaction

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A two-dimensional position sensitive multi-stage detection system with a wide dynamic range for a heavy ion reaction is described in this paper. It consists of four parts: a longitudinal electric field gas filled Ionization Chamber (IC), a Position Sensitive Silicon Detector (PSSD) (45 mm × 45 mm, 400 μm), a large area PIN Silicon Photodiode (SPD) (48 mm × 48 mm, 300 μm), and a 16 element CsI(Tl) scintillation detector array. The energy resolutions for IC and PSSD tested with α source ^{241}Am(5.486 MeV) are 3% and 2.6%, respectively. The energy dynamic range for α particle detection is about 2-130 MeV, and the fragments with Z Values from Z = 2 to Z = 21 are identified in the reaction of 25 MeV/u ^{40}Ar+^{115}In. The Z resolving power is $Z/\Delta Z \approx 44.5$ (FWHM) for Z = 18. The position resolution of PSSD is 0.86±0.03 mm (FWHM).

Key words: particle identification, longitudinal electric field, energy resolution, position resolution.

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1. INTRODUCTION

The heavy ion reaction at intermediate energy is one of important fields in nuclear physics studies during the past decade. With the increasing bombarding energy of the projectile in the nucleon-nucleon

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Received on March 15, 1995. Supported by the National Natural Science Foundation of China and the Science Foundation of the Chinese Academy of Sciences.

collision at intermediate energy, such as in the peripheral reaction, the central reaction, the formation of the hot nuclei accompanied by light particle emission, a rapid increase of the exit channels is observed and a much broader dynamical distribution exists in the momentum space, and the reaction products become more and more complicated. The design and construction of the detector is therefore becoming more and more complicated and precise. The multi-stage detection system with a large dynamic range has many distinguishing features, such as a low energy threshold, wide dynamic range of energy, good resolutions for energy, position, and atomic number [1]. It can be used not only in the inclusive experiments, but also in the exclusive ones for the interferometry studies of the emitted charged particles. Furthermore, it can also be chosen as the element of the multi-stage detector to enlarge the covered solid angle to a great extent to satisfy the experiment's requirements [2,3]. For the investigation of the sequential decay of the projectile-like fragments and particle interferometry in the heavy ion reaction at intermediate energy as well as the study of the nuclear reaction using radioactive ion beams, we have developed a two-dimensional position sensitive multi-stage detection system with wide dynamic range. In this paper the detector construction, its performance, and some results in the reaction of 25 MeV/u^{40}Ar+^{27}Al, ^{58}Ni, ^{115}In are reported.

2. CONSTRUCTION AND PERFORMANCE OF MULTI-STAGE DETECTION SYSTEM WITH A LARGE DYNAMIC RANGE

The multi-stage detection system with a large dynamic range is one of the main parts of the high performance detector system of the experimental terminal with large area position sensitive ionization chambers at HIRFL [4]. It is composed of four parts: a longitudinal electric field gas-filled Ionization Chamber (IC), a Position Sensitive Silicon Detector (PSSD), a large area PIN Silicon Photodiode (SPD), and a 16 element CsI(Tl) scintillation detector array. Figure 1(a) shows the schematic diagram of the multi-stage detection system.

2.1. Ionization chamber

The longitudinal field gas-filled ionization chamber, in which the electric field is parallel to the trajectories of the incident particles, is composed of three electrodes of the cathode, the Frisch grid, and the anode. It is called the Bragg curve detector [5] when it serves as a full stopping ionization chamber to measure the reaction products in heavy ion reaction at low energy. At the intermediate energy, however, the situation is quite different. In such a case, the IC can only be used as a transmission detector because the energy of reaction products coming from the projectile fragmentation is much higher. It can be used as the first stage of the multi-stage detection system to substitute the thin Si semiconductor detector so that the threshold for the whole detection system is reduced and the dynamic range of the system is enlarged.

Both the entrance and exit windows are 6 μm thick mylar foil. The distance between the cathode and the Frisch grid is 100 mm, while the grid-anode distance is 10 mm. The cathode and the Frisch grid consist of parallel gold-plated tungsten wires with the diameters of 25 and 70 μm, respectively, spaced 1 mm apart. This gives the geometrical transparencies for the cathode and Frisch grid 97.5% and 93%, respectively. The anode is a 1.5 μm aluminized mylar foil. The estimated grid screening inefficiency [6] is $\sigma \approx 2.4\%$. The main body of the square-shaped potential guard rings is made of the printed circuit board with the guard rings (width and spacing 2 and 7 mm, respectively). A resistor chain (10MΩ $\times$ 11) is connected to the guard rings in order to achieve a homogeneous electric field. The active volume of the ionization chamber is 45 mm $\times$ 45 mm $\times$ 11 mm. P10(90%Ar, 10%CH_4) gas is adopted as the working gas which pressure is adjusted by a automatic control system. When the ionization chamber is run at 48.3 kPa, $V_k = -1000$ V, $V_a = 350$ V, and the Frisch grid is grounded, the energy resolution for an ^{241}Am(5.486 MeV) α-source is obtained as ~3%. The other details of the ionization chamber can be found in Ref. 7.

2.2. Large area two-dimensional position sensitive silicon detector

The two-dimensional PSSD with a large effective area provides a simultaneous measurement of the energy and the position of the incident particles. It has good energy and position resolution. The effective area of the PSSD (Hamamastu 3S3064) is 45 mm × 45 mm and the thickness is 400 μm. As shown in Fig. 1(b), the base material is an ion-implanted n-type silicon. The boron-implanted layer serves as the resistive anodes with the surface resistance R_s for charge division and forms the p-n junction. On each side of the anode there are four resistive strip electrodes with the resistance of R_l formed by the ion-implanted method. Position signals can be extracted from the aluminum evaporated contacts P_i (i = 1, 2, 3, 4) which are at four corners of the anode while the gold evaporated contact at the back of the PSSD is applied as the electrode for the energy signal measurement. The typical full depletion voltage is V_{base} = 100 V. The energy resolution for ^{241}Am (5.486 MeV) α-source is 2.6%(FWHM) when the shaping time of the main amplifier of energy channel is selected as 2 μs.

The two-dimensional position (x,y) of incident particle in the PSSD (side length L) can be derived by the charge division method. The total charge Q_0 generated on the resistive anode is the sum of the charge Q_{pi} delivered to the corner contacts P_i (i = 1, 2, 3, 4), which is directly proportional to the energy deposited in the detector. The charge Q_{pi} is given as:

$$\begin{cases} Q_0 = Q_{P1} + Q_{P2} + Q_{P3} + Q_{P4}, \\ Q_{P1} = \dfrac{Q_0}{L^2}(L-x)(L-y), \quad Q_{P2} = \dfrac{Q_0}{L^2}(L-x)y, \\ Q_{P3} = \dfrac{Q_0}{L^2}x \cdot y, \quad Q_{P4} = \dfrac{Q_0}{L^2}x(L-y). \end{cases} \tag{1}$$

From the above equation, the two-dimensional position of the incident particle is deduced as:

$$\begin{cases} X/L = Q_{P3}/(Q_{P2}+Q_{P3}) = Q_{P4}/(Q_{P1}+Q_{P4}), \\ Y/L = Q_{P2}/(Q_{P1}+Q_{P2}) = Q_{P3}/(Q_{P3}+Q_{P4}). \end{cases} \tag{2}$$

The position resolution for ^{241}Am(5.486 MeV) α-source is 1.9 mm (FWHM) when the shaping time of the main amplifier of the position channel is selected as 1 μs.

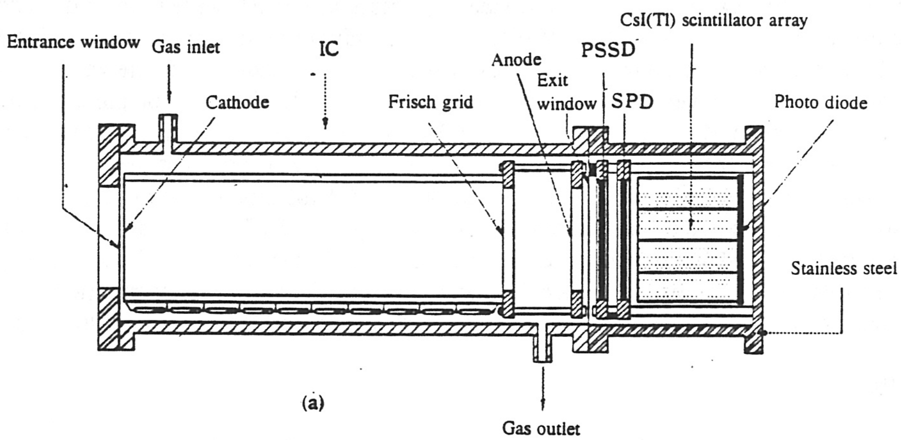


Fig. 1(a)
The schematic diagram of the multi-stage detection system.

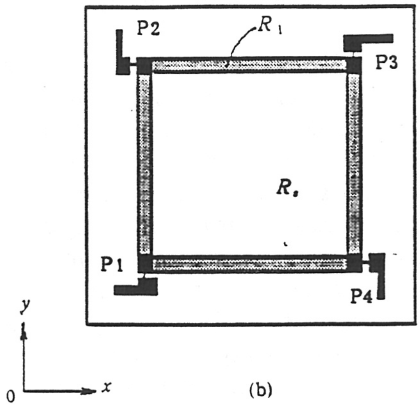


Fig. 1(b)
The schematic diagram of the position sensitive silicon detector.

2.3. Large area silicon photodiode and 16 element CsI(Tl) scintillator array

The SPD of the type 4S1467, which is supplied by Hamamastu Photonics, Co., has an active area of 48 mm × 48 mm and a thickness of 300 μm. Its full depletion voltage is V_{base} = 80 V. The SPD is used as the third stage ΔE detector in our configuration. 16 unit CsI(Tl) detectors are assembled to make a 4×4 square-shaped structure. Each CsI(Tl) crystal, which has the size of 10 mm × 10 mm × 20 mm, is polished on the front and rear face. Each side of the crystal is wrapped with several layers of 0.1 mm Teflon tape, the front fact is covered with 1.5 μm aluminized Mylar foil, and the rear face is coupled to the photodiode (Hamamastu S1790-02) with the silicon oil. The scintillator detector array is served as the residual energy detector so as to give the information of the energetic charged particles.

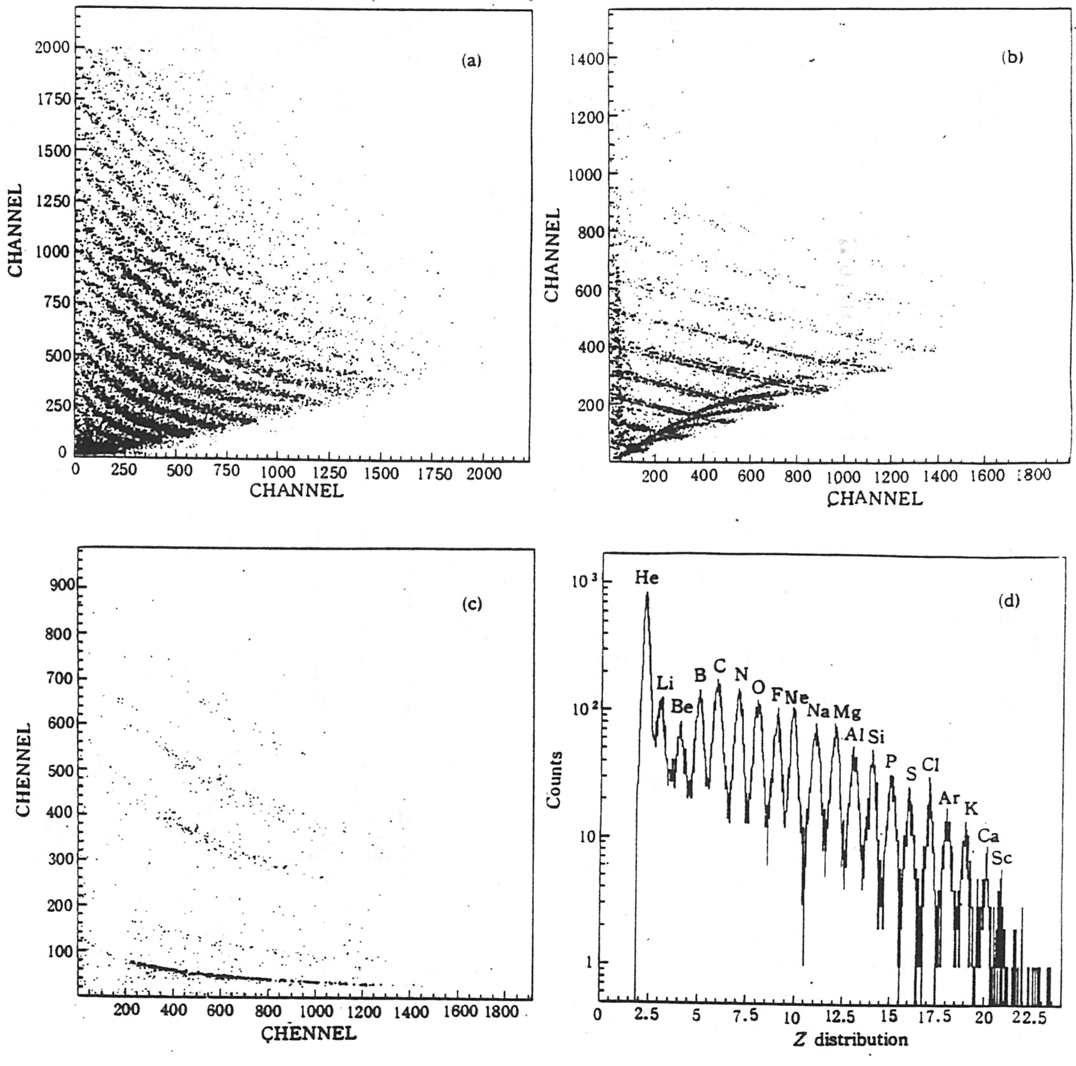
3. RESULTS OF HEAVY ION REACTION AT INTERMEDIATE ENERGY

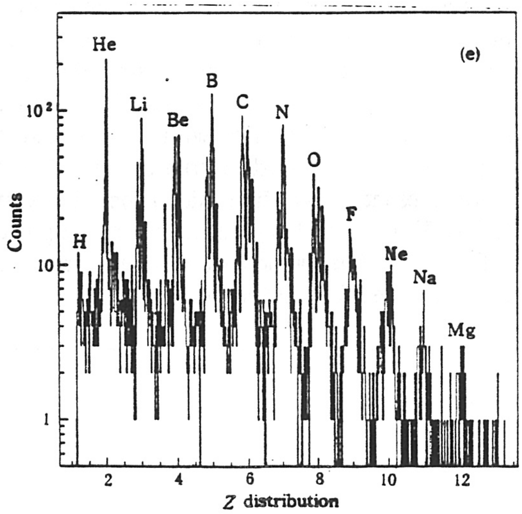
3.1. Detector layout and signal processing

For the investigation of the sequential decay of the projectile-like fragments and studies of particle interferometry, two sets of the multi-stage detectors at HIRFL were used in our experiment to measure the reaction products of 25 MeV/u ^{40}Ar beam bombarding on various targets. The detectors were placed 30 cm away from the target at angles of ±17.5° on the table inside the vacuum scattering chamber, where each IC covers an effective angle range of 8.6°. Voltages for the cathode and the anode of the ΔE IC were V_k = −900 V and V_a = 300 V, respectively, so the reduced electric field was E/p = 2.48 (V·cm^{-1}kPa^{-1}). In such a case, the maximum electron drift velocity is reached in order to obtain an optimal collection of electrons. Standard NIM modules supplied by the ORTEC company were utilized to handle the energy and position signals of IC, PSSD, and the CsI(Tl) array. The strobe signal of CAMAC was triggered by the time signal coming from PSSD. The experiment data were recorded event by event on magnetic tapes with the GOOSY data acquisition system. The software packages of CERNLIB and PAW were adopted in the off-line analysis of the data.

3.2. Results

Figure 2(a)-(c) give respectively the scatter plots of IC vs. PSSD, PSSD vs. SPD, and SPD vs. one element of the CsI(Tl) crystal array in the reaction of 25 MeV/u ^{40}Ar+^{115}In(3.936 mg/cm^2). The corresponding Z spectra obtained after the linearization of the scatter plots are shown in Figs. 2(d)-(f). The elements from $Z = 2$ to $Z = 21$ are clearly identified by the detectors. A Z resolving power of $Z/\Delta Z = 44.5$ for argon has been achieved. Most of the heavy reaction products are stopped in IC, PSSD, and SPD. CsI(Tl) array gives the information of residual energy for the energetic light-charged particles. The energy dynamic range for α-particles were found to be 2-130 MeV in the off-line analysis. In the position measurement of PSSD, a copper collimation plate with a 9×9 matrix of pinholes, with interval and diameter 5 and 1 mm, respectively, was placed in front of the PSSD. The amplifier shaping time was taken to be 1μs. Figure 3(a) presents a two-dimensional position scatter plot for the emitted particles in the reaction of ^{40}Ar(25 MeV/u)+^{27}Al(1 mg/cm^2). One of the position spectra projected onto the x-direction is shown in Fig. 3(b), from which we can see that a good position resolution (0.86 ± 0.03 mm FWHM) has been achieved for the PSSD.





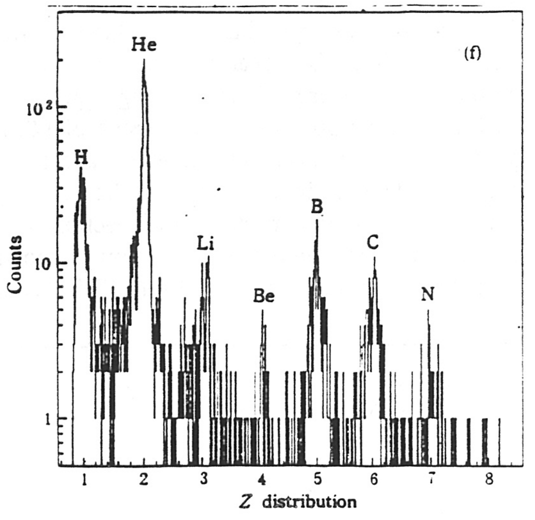


Fig. 2

In the reaction of ^{40}Ar(25 MeV/u)+^{115}In, the scatter plots and the corresponding Z spectra after linearization for the multi-stage detection system at the angle of θ_{lab} = 17.5°. (a), (d) IC vs. PSSD; (b), (e) PSSD vs. SPD; (c), (f) SPD vs. one element of the CsI(Tl) scintillator array.

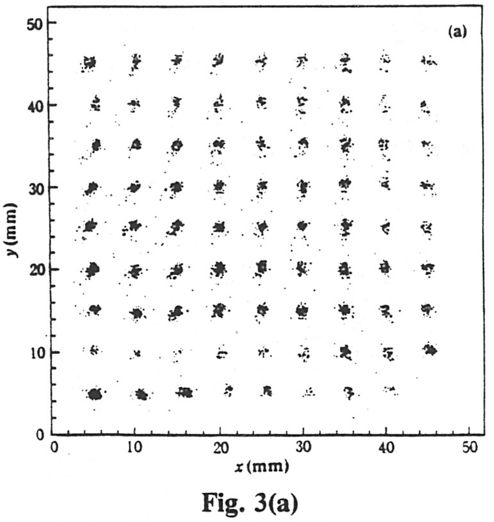


Fig. 3(a)

The two-dimensional position scatter plot for the emitted particles of ^{40}Ar(25 MeV/u)+^{115}In at the angle of θ_{lab} = 17.5°.

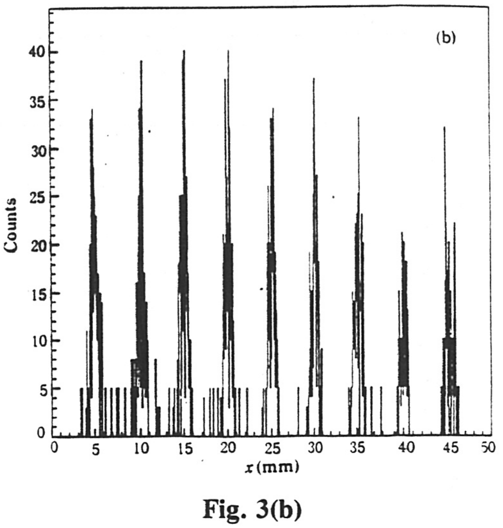


Fig. 3(b)

One of the position projection spectra of Fig. 3(a).

4. CONCLUSIONS

In this article we have presented the design of a multi-stage detection system with a large dynamic range and its application in the heavy ion reaction. The IC, which serves as the first stage of the detection system, has an homogeneous detection medium whose equivalent thickness is changeable, so the energy threshold for the whole detection system is reduced and in the meantime the dynamic range for the detection system is enlarged. The precise energy and position information for the reaction products can be measured with the PSSD+SPD. The information associated with the energetic charged particles are given by the CsI(Tl) array. In conclusion, the detection system has good resolutions for atomic number, energy, and position. It is suitable for the measurement of complex fragments produced in the heavy ion reaction.

The improved detection system, together with other light particle detectors, the β- and γ-rays detectors, is one part of the small detection system with the characteristics of multi-function and high resolution at the radioactive ion beam line at HIRFL [8]. They will be used in the studies of the nuclear structure, the decay properties, and the nuclear spectroscopy of RIB.

ACKNOWLEDGMENT

The authors would like to thank the operators for providing us with an ^{40}Ar beam of excellent quality.

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