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NE102A + CsI(Tl) + PMT Detector Telescope for Intermediate Energy Heavy Ion Reactions

Qi Zhong, Guo Zhongyan, Zhan Wenlong, Zhou Jianqun, Liu Guanhua, Zhang Wansheng, Wang Jinchuan, Lin Yuangen, Zhu Yongtai, Xu Hushan, and Xie Yuanxiang

(Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China)

The paper describes the structure and performance of the phoswich telescope made of 1 mm thick scintillator NE102A and 40 mm thick CsI(Tl). The front area of the CsI(Tl) is 24 mm × 24 mm and back area is 37 mm × 37 mm. The $Z = 1$ isotopes p, d, t, and all other detected fragments have been separated clearly by using the traditional fast-slow gate QDC method.

Key words: intermediate energy heavy ions, phoswich telescope, particle identification.

1. INTRODUCTION

The nuclear reaction mechanism is an important subject in intermediate energy heavy ion reaction experiments [1]. To understand the mechanism of various reactions, as many as possible reaction products and their origins must be identified. In this energy region, the energy spread of the products is very large, the produced elements and isotopes are distributed widely and the reaction product distribution in space and in time is very complex. In order to detect these particles, many kinds of detectors have been developed, e.g., the multi-fold silicon semiconductor telescope [2], the IC+Si+CsI(Tl)+PD combined detector telescope [3], the IC+Si+CsI(Tl)+PMT logarithmic density

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detector telescope [4], the fast-slow plastic scintillator detector telescope, the heavy ion TOF telescope, etc. Using these detectors, researchers have constructed 4π equipment to detect all the particles produced, such as the INDRA in GANIL, the FOPI in GSI, and the MINIBALL in MSU.

The silicon semiconductor detector is better in energy resolution and particle identification, and its time response is also good. However, if the thickness is thinner than 5 μm or the depleted layer is thicker than 1 mm, it would be difficult to produce and expensive in price, and the size of the silicon detector is also limited. Although the energy resolution and time response of the gas ionization chamber is not as good as the semiconductor detector, and the stopping power is poor, it can be made thinner and the thickness is even and adjustable, the detecting threshold is also low; it is therefore suitable for heavy fragments detection. It is easy to produce with a desirable size and cheap price. The scintillator detector has a fast time response (e.g., NE102A, NE115, BC-400, BC-418) and a high stopping power (e.g., BGO, CsI(Tl), BaF_2). It is easily cut into arbitrary shapes or sizes or cover large solid-angles. The luminous efficiency is higher and the performance of anti-radioactivity is also good. It is an ideal choice for the residual energy detector in an intermediate energy heavy ion detector telescope.

This paper reports on a phoswich detector, which consists of a piece of fast plastic scintillator NE102A and a CsI(Tl) crystal. The decay time of NE102A is 2.4 ns, the peak wavelength of emitting spectrum is 400 nm. The CsI(Tl) has two decay components, one has the decay time 400 — 700 ns and the other 7 μs; its peak wavelength is 550 nm. This phoswich detector is read out by a PMT R1666, and the fast-slow gate QDC integration method is used to identify the particles.

2. STRUCTURE AND PRINCIPLE OF THE DETECTOR

2.1. Basic structure

This detector unit is composed of a fast plastic scintillator NE102A (1 mm thick and 24 mm × 24 mm in size), a CsI(Tl) scintillator (the surface is 24 mm × 24 mm in front, 37 mm × 37 mm in back, and 40 mm thick), a light guide and a Hamamatsu R1666 PMT; the basic structure is shown in Fig. 1.

Because the CsI(Tl) scintillator and the PMT have different shapes in their contact surfaces, we used a light guide made of aerial Plexiglas to connect them. By simulating the photon transportation in the light guide with the Monte Carlo method, we determined its optimal shape and size. The light guide is cone-shaped and 40 mm thick. The front surface's diameter is 16 mm equal to the R1666's

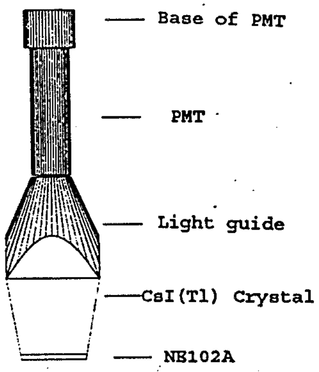

Fig. 1
The structure of a detector unit.

photo-cathode, and the back surface fits the CsI(Tl). The light guide, the CsI(Tl), and the PMT were coupled with a silica gel. The front surface of the detector is covered by a 1.5 μm aluminum foil, and the body is wrapped with multi-layers of 0.1 mm Teflon.

Because the detector is used in a high vacuum environment, and the produced heat is difficult to conduct out, we designed the base of the PMT with a lower power consumption which can ensure that the PMT works properly in a wide current range for a long time. The static working current of the PMT is 0.75 mA. The body is made of a soft iron tube 20 mm in diameter to protect it from light and the electromagnetic field, and the surface was treated blue.

2.2. Principle of the fragment identification

The anode output pulse of the PMT is produced by the light component of NE102A, and the fast and low components of CsI(Tl). The total signal output is

$$\begin{aligned} L_{\text{out}} &= L_{\text{NE102A}} + L_{\text{fast}} + L_{\text{slow}} = \int_0^t \left(k_1 e^{-\frac{t}{\tau_{\text{NE102A}}}} + k_2 e^{-\frac{t}{\tau_{\text{fast}}}} + k_3 e^{-\frac{t}{\tau_{\text{slow}}}}\right) \mathrm{d}t \\ &= \int_0^t \left(k_{\text{NE102A}} i(t) + k_{\text{fast}} i(t) + k_{\text{slow}} i(t)\right) \mathrm{d}t, \end{aligned} \tag{1}$$

here, k_1, k_2, k_3 are coefficients related to ionization density, τ_{NE102A}, τ_{fast}, τ_{slow} are decay time constants, and k_{NE102A}, k_{fast}, k_{slow} are numerical parameters.

The signals are divided and integrated by using QDC; the charge integrations are controlled by the fast-slow gate with different time intervals Δt_{NE102A}, Δt_{fast}, Δt_{slow}:

$$\begin{cases} Q_{\text{NE102A}} = k_{\text{NE102A}} \int^{\Delta t_{\text{NE102A}}} i(t)\,\mathrm{d}t, \\ Q_{\text{fast}} = k_{\text{fast}} \int^{\Delta t_{\text{fast}}} i(t)\,\mathrm{d}t, \\ Q_{\text{slow}} = k_{\text{slow}} \int^{\Delta t_{\text{slow}}} i(t)\,\mathrm{d}t. \end{cases} \tag{2}$$

Normally, the combination of Q_{NE102A}-Q_{fast} is fit to identify heavy fragments and the combination of Q_{fast}-Q_{slow} is suitable for light ones. The identification of particles is based on the Bethe-Bloch formula: $\Delta E \cdot E \propto MZ^2$. For heavy fragments, $Q_{\text{NE102A}} \propto \Delta E$, $Q_{\text{fast}} \propto E$; for light ones, $Q_{\text{fast}} \propto \Delta E$, $Q_{\text{slow}} \propto E$.

3. RESULTS OF EXPERIMENTS

This detector has been tested on HIRFL; Fig. 2 is the electronics layout used. The signal output from the PMT's anode is divided into three routes: one enters the Philips 7166CAMAC QDC to form the ΔE signal, the second enters the 7166QDC as E signal and the last one enters a CFD to produce a time signal, which generates different fast-slow gate, delayed by different times, to control the start time and the time interval of the QDC integration.

In the reaction ^{40}Ar+^{58}Ni with incident energy 30 MeV/nucleon, the detector was placed 257 mm apart from the center of the target, the pole angles in the laboratory system were $17° \leq \theta \leq 18°$, $\varphi = 10°$. When the width of the fast gate was 40 ns, the slow gate was 600 ns and delayed by 200 ns, the two integrated signals correspond to the Q_{NE102A} and Q_{fast}, respectively. Figure 3 is the measured ΔE-E 2D scatter plot. Because the detector was far away from the grazing angle, the projectile-like fragments had not been detected.

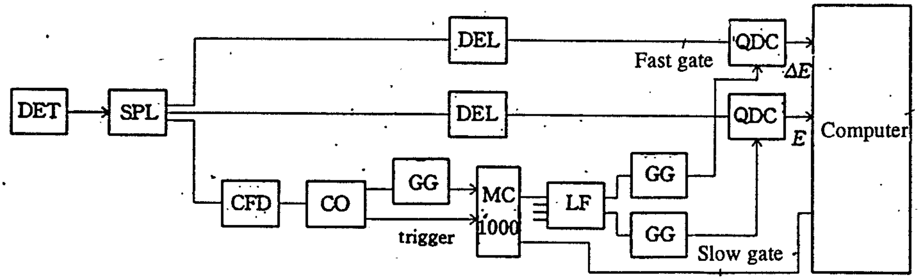

Fig. 2

The electronics layout used for one detector unit.

DET: detector, SPL: signal split, DEL: delay, CFD: constant fraction discrimination, CO: coincidence, GG: gate generator, LF: logic fan-in/fan-out, QDC: charge-digital conversation, MC1000: gate signal controller.

The data were acquired by the Juhu on-line acquisition program and recorded on magnetic tapes in the event mode. The off-line data analysis used the KVI's Pax data analysis program. Fitting the data of the 2D scattering plot, implementing linearzation and projecting it to the Z axis, we obtained the Z distribution of elements (Fig. 4). From the figure, the $Z = 1$ isotopes p, d, t, and all the fragments of $Z \geq 2$ can be identified clearly.

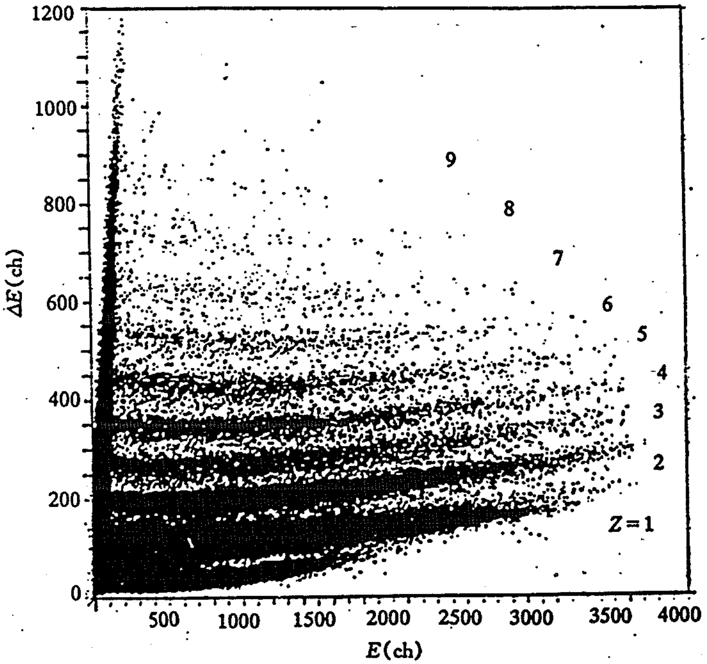

Fig. 3

ΔE-E 2D scatter plot.

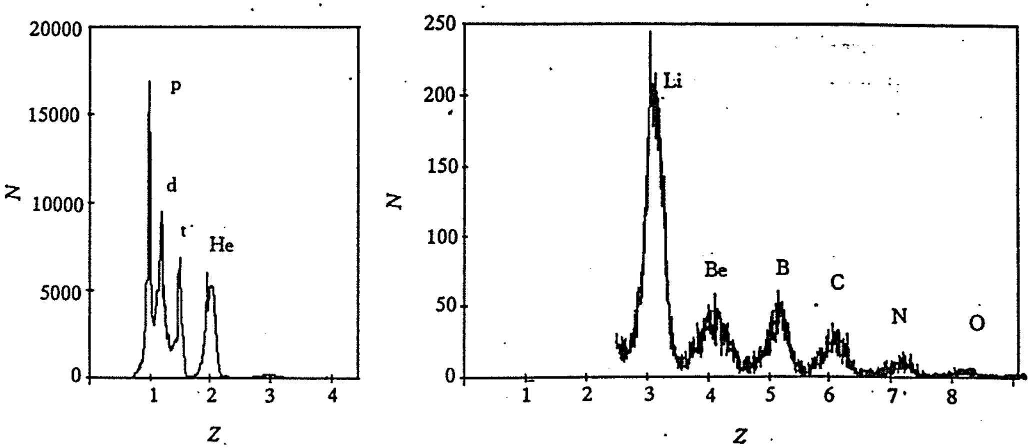

Fig. 4
The projection of ΔE-E to Z and the elements identification.

4. DISCUSSION

The CsI(Tl) scintillator has a large density, a high luminous efficiency, and a good energy resolution; the emitting light spectrum can fit the PMT well. It is the best candidate for the residual energy detector in an intermediate energy heavy ion telescope. Using the fast and slow components of the detector, the light-charged particles ($Z \leq 2$) can be identified, either by the fast-slow gate QDC method or by the zero-crossing time method. The use of NE102A increases the fast components of the light pulse, sharpens the leading edge of the pulse; the identification capability is improved so that it can be used to identify not only light particles, but also heavy fragments. Thinner NE102A detectors, e.g., 500, 200, 100, 50, 20 μm, determined by the width of the measured particles's Z distribution, are needed to decrease the detecting energy threshold. The thinner the NE102A detector, the heavier the particles that can be identified.

Using an ionization chamber or a silicon semiconductor detector in front of this detector can further decrease the detection threshold, improve the identification capability, and can be used to identity heavier fragments.

Because the time response of CsI(Tl) is not good, it cannot be used in forward angles with a high counting rate, but in angles from 10° to 150°, it is used as a residual energy detector for nearly all kinds of fragments telescopes. Compared with BGO and BaF_2, CsI(Tl) has a good energy resolution since it has high luminous efficiency and its wavelength fits the PMT or PDT well.

REFERENCES

[1] R. Wada *et al.*, *Nucl. Instr. Meth.*, **359**(1992), p. 316.
[2] Guo Zhongyan *et al.*, *High Energy Phys. and Nucl. Phys.* (Chinese Edition), **19**(1995), p. 865.
[3] J. Alarja, A. Dauchy, A. Giorni *et al.*, *Nucl. Instr. Meth.*, **A242**(1986), p. 352.
[4] R.T. Desouza, N. Carlin, Y.D. Kim *et al.*, *Nucl. Instr. Meth.*, **A295**(1990), p. 109.
[5] J.C. Steckmeyer *et al.*, *Nucl. Instr. Meth.*, **A361**(1995), p. 472.