Property measurement of the CsI(Tl) crystal prepared at IMP*

CHEN Ruo-Fu(陈若富)[1,2;1)] XU Hu-Shan(徐瑚珊)[1] FAN Rui-Rui(樊瑞睿)[1,2] ZHAN Wen-Long(詹文龙)[1]
XIAO Guo-Qing(肖国青)[1] LI Song-Lin(李松林)[1] WANG Jian-Song(王建松)[1]
HUANG Tian-Heng(黄天衡)[1,2] ZHENG Chuan(郑川)[1,2] YU Yu-Hong(余玉洪)[1,2]
WANG Meng(王猛)[1] HU Zheng-Guo(胡正国)[1] YE Fei(叶飞)[1] WANG Yue(王玥)[1,2]
JIA Fei(贾飞)[1,2] YUE Ke(岳珂)[1,2] OUYANG Zhen(欧阳珍)[1,2]

1 (Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China)
2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract Large-sized CsI(Tl) single crystals, $\sim\phi$100 mm×350 mm, have been grown successfully, and this CsI(Tl) coupled with PD has been successfully utilized at RIBLL (the Radioactive Ion Beam Line in Lanzhou) to measure the energy of heavy ions as a stopping detector. The performances of CsI(Tl) detector coupled with PD and APD have been tested and compared, including the temperature dependence of scintillating light yield.

Key words CsI(Tl), light yield, energy resolution, temperature dependence

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1 Introduction

The thallium doped cesium iodide (CsI(Tl)) or the pure cesium iodide (CsI) crystal have been widely used in nuclear and particle physics experiments, and a monograph about CsI crystal has come forth in 1960's [1]. The CsI(Tl) crystal is regarded as an all-important material for its excellent characters in high energy physics experiments, and used as the electro-magnetic calorimeters (EMC) to measure the energy and position of high energy γ-ray and electron[2—6]. A similar crystal calorimeter has also been proposed for the Hadron Physics Lanzhou Spectrometer (HPLUS) at the Institute of Modern Physics, the Chinese Academy of Sciences (IMP) which will focus on the hadron physics with the proton beam up to 3.7 GeV/c in the Cooling Storage Ring (CSR)[7].

In this case, a program to grow CsI(Tl) crystal was initiated at IMP two years ago. Fortunately, the CsI(Tl) crystal with large size has been grown successfully by the Bridgman technique. In this paper, the status of the CsI(Tl) crystal growth at IMP and the performances of the home-made CsI(Tl) crystal will be described.

2 Growth of the crystal

The CsI(Tl) crystal is grown by the Bridgman technique. The purity of the super-dry raw materials,

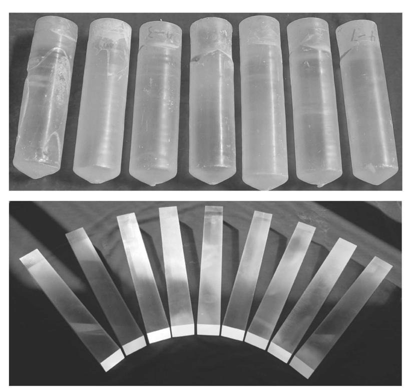

Fig. 1. The samples of home-made crystals (left) and manufactured crystal detector (right) with the 40 mm×40 mm×300 mm for the upgrade of STAR program.

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1) E-mail: chenruofu@impcas.ac.cn

from Chemetall GMBH Ldt., Germany, is 99.999%. The large-sized crystal (∼ϕ100 mm×350 mm) has been grown successfully in about 45 days, and the raw crystal can be manufactured well according to the experimental requirements. Fig. 1 shows the samples of raw crystal and the manufactured crystal for the STAR upgrade program with the dimensions of 40 mm×40 mm×300 mm.

3 Light output and energy resolution test with gamma source

3.1 Coupled with PMT

To compare the performance of the home-made CsI(Tl) crystal with the sample provided by the other company, some cylindrical standard samples with ϕ1 inch×1 inch dimensions have been manufactured.

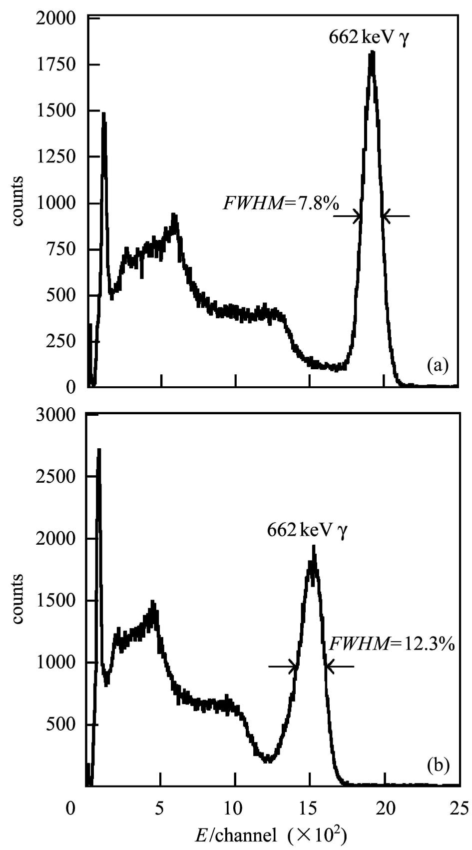

Fig. 2. The typical energy spectrums for 662 keV of the home-made standard samples (a) and the sample provided by the other company (b).

All of the standard samples have been polished and wrapped by one layer of Teflon on the sides and four layers on the (back) reflecting end. The standard samples are put into aluminum cylinders with quartz film to couple the readout ends of the standard samples by air coupling. A photomultiplier tube (PMT) (HAMAMATSU, R7724) has been used to read out the scintillating light by air coupling. The conditions of working voltage of the PMT, electronics and temperature in the laboratory are kept constant during the test. The signal from the PMT is fed to an amplifier (ORTEC 572) and then to ADC (PHILLIPS, 7164).

The results show that the light output of most of the home-made standard samples is over 20% higher than that provided by the other company. The energy resolution of the home-made standard samples is about $\Delta E(FWHM)/E = 8\%$ for 662 keV γ-ray, while that of the sample provided by the other company is 12%—13%. Fig. 2 shows the typical energy spectrums of the home-made standard samples and that provided by the other company.

3.2 Coupled with PD

A cubic crystal sample with 10 mm×10 mm× 10 mm dimensions has been manufactured to fit the sensitive area of photodiode (PD) S3590-01 from HAMAMATSU. The CsI(Tl) sample coupled with PD is put into a vacuum chamber, and the temperature is controlled by a cryogenics system (Thermo Haake K15，Thermo Haake D30) with the precision of ±0.1 ℃. It is radiated with the 662 keV γ-ray from a ^{137}Cs radiation source. The signal from the PD is fed to a preamp (ORTEC, 142B) and then to an amplifier (ORTEC, 572), and the preamp and the amplifier are in room temperature (25 ℃).

A thermometer, Pt100, is employed to monitor the crystal temperature. Optical grease (BICRON, BC630) is used to couple the CsI(Tl) and PD, and CsI(Tl) is wrapped with 3 layers of light diffusion materials (Teflon) except for the readout surface.

Figure 3 gives the typical energy resolution, $\Delta E(FWHM)/E$=11.3%, for 662 keV γ-ray at 25 ℃.

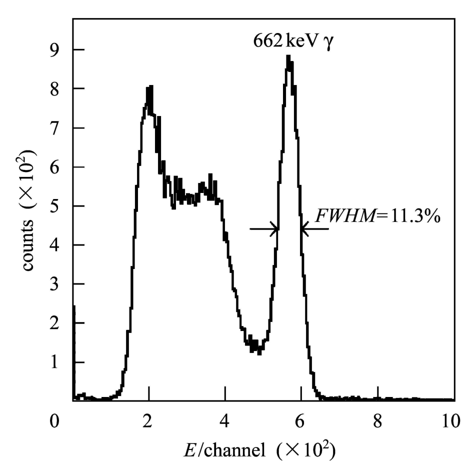

Fig. 3. The typical energy spectrum of CsI(Tl) detector coupled PD at 25 ℃ temperature.

3.3 Coupled with APD

The CsI(Tl) sample coupled with an APD (HAMAMATSU, S8664-1010) has been tested. The test condition and method are the same as those described in Section 3.2. The working voltage in the test is 400 V.

Figure 4 shows the temperature dependence of signal from CsI(Tl) crystal coupled with APD at 400 V typical working voltage. In most of the room temperature range, the factor of temperature dependence is about −3.35%/ ℃, and the energy resolution varies between 5% and 6% for 662 keV γ-ray. Fig. 5 shows the typical energy spectrum, $\Delta E(FWHM)/E$=5.1%, at 25 ℃.

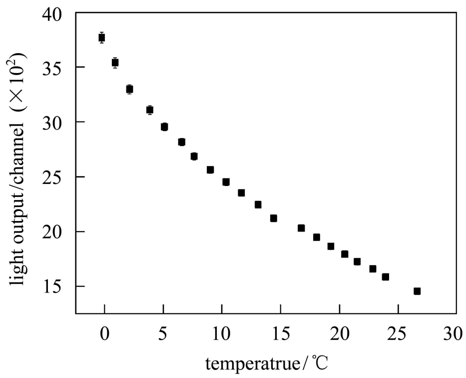

Fig. 4. The temperature dependence of light output of CsI(Tl) crystal coupled APD. The error bar is FWHM of the energy spectrum at every temperature point.

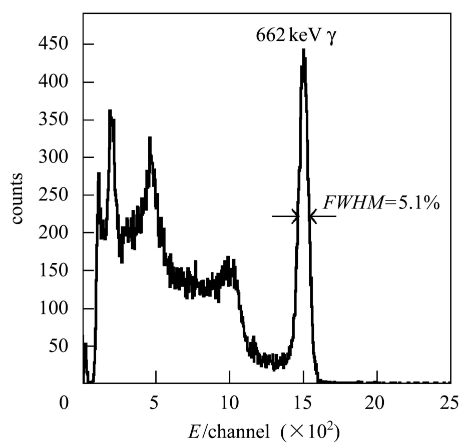

Fig. 5. The typical energy spectrum of CsI(Tl) crystal coupled APD at the temperature of 25 ℃.

4 Performance of energy measurement for heavy ions

An energy detector made by home-made CsI(Tl) crystal with 20 mm×20 mm×20 mm dimensions and a PD (HAMAMATSU, S3204-3) is used to measure the deposit energy of heavy ions at the Radioactive Ion Beam Line in Lanzhou (RIBLL)[8].

The primary beam of $^{58}Ni^{24+}$ with 50 MeV/u energy provided by the Heavy Ion Research Facility of Lanzhou (HIRFL) at IMP impacts the 56 μm primary target Ta. The fragments selected by $B\rho$ method can be transmitted to F_4 and detected by the CsI(Tl) detectors. A set of TOF system composed of two scintillating films (C_9H_{10}) with 10 μm thickness gives the time of flight of the fragments, located at the first (F_2) and second focal point (F_4) respectively. A telescope system composed by a gas ionization chamber (IC) and a energy stopping detector made by CsI(Tl) crystal coupled with PD gives ΔE and E, respectively. The fragments can be identified by the methods of ΔE-E, $B\rho$-ΔE-TOF or $B\rho$-E-TOF.

Figure 6 shows the contour plots of ΔE vs. E and E vs. TOF, and the value of $B\rho$ is set according to $^{55}Ni^{28+}$. In order to get the particle responses of the CsI(Tl) detector, the time range between 220 and 224 ns of TOF was chosen.

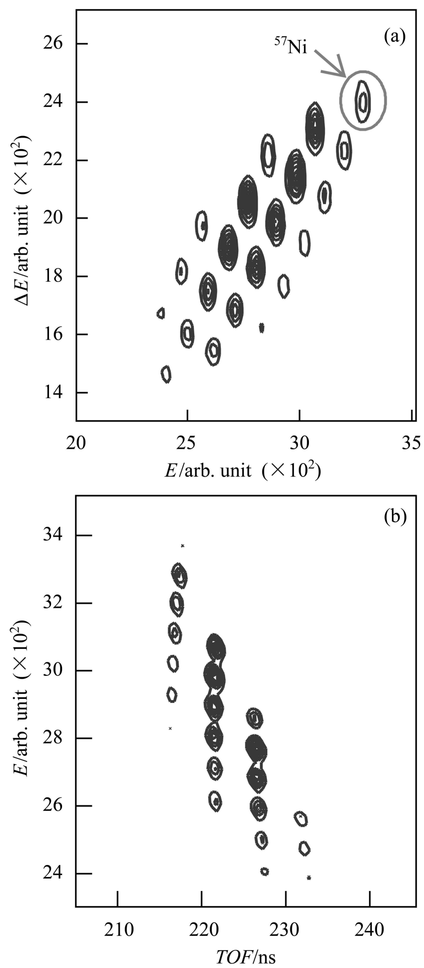

Fig. 6. The ΔE-E contour plot (a) and the E-TOF contour plot (b) from the reaction of $^{58}Ni^{28+}$ beam with 50 MeV/u energy on the Ta target with 56 μm.

The energy resolution of CsI(Tl) crystal detector can be influenced by δE_i, δE_{TOF}, δE_{IC}, δE_{Al}, which stand for the contributions of energy straggle from particle itself, scintillating films of the TOF system, the window and gas of the IC, and the incident Al window of CsI(Tl) crystal detector, respectively. The intrinsic energy resolutions for particles can be calculated excluding the above terms and listed in Table 1.

Table 1. The measured and intrinsic energy resolution of some particles detected by CsI(Tl) detector coupled with PD.

incident particles	energy/MeV	channel	energy resolution ($FWHM$%)	intrinsic E resolution ($FWHM$%)
^{56}Co	1698	3068.2	1.46	1.45
^{54}Fe	1642	2983.1	1.56	1.55
^{52}Mn	1585	2896.0	1.64	1.63
^{50}Cr	1527	2805.6	1.67	1.65
^{48}V	1469	2711.3	1.56	1.55
^{46}Ti	1410	2616.0	2.06	2.06

A good energy resolution of CsI(Tl) detector for heavy ions with the intermediate energy, <2%, is obtained.

5 Temperature dependence of the light yield

For studying temperature dependence of light-yield of CsI(Tl) crystal in room temperature range, a test with CsI(Tl) crystal coupled with PD was introduced. The test details have been described in Section 3.2.

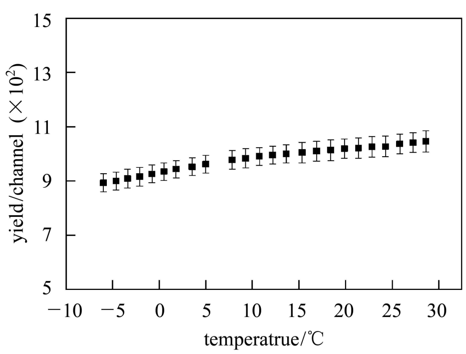

Fig. 7. The temperature dependence of light-yield of CsI(Tl) crystal. The error bar is $FWHM$ of energy spectrum at every temperature point.

Assumed that the light collection efficiency and the quantum efficiency of PD do not depend on the temperature, the change of the signal amplitude just reflects the temperature dependence of the light-yield of the crystal.

Figure 7 gives the temperature dependence of light-yield of the CsI(Tl) crystal, and the slope is about 0.67%/ ℃ between −2℃ and 8 ℃, and 0.33%/ ℃ between 8 ℃ and 25 ℃.

It should be noticed that the temperature dependence of light-yield of CsI(Tl) crystal in this test is consistent well with the results in References[2, 9], but not consistent with the Valentine's results[10]. It may be caused by the quality of the crystal samples provided by different companies.

6 Summary and discussion

The status of the CsI(Tl) crystal growth at IMP, and the performances of the home-made CsI(Tl) detectors have been reported.

(a) The yield of home-made CsI(Tl) is obviously better than that provided by the other company.

(b) A cubic CsI(Tl) sample with 10 mm×10 mm×10 mm dimensions coupled with PD and APD can provide a good energy resolution for 662 keV γ-ray, $\Delta E(FWHM)/E = 11.3\%$ (coupled PD), $\Delta E(FWHM)/E = 5.1\%$ (coupled APD), at 25 ℃.

(c) The temperature dependence of CsI(Tl) light yield is 0.33%/ ℃ in the room temperature.

(d) The temperature dependence of CsI(Tl)+APD detector is about −3.35%/ ℃ in most of the room temperature range.

(e) The CsI(Tl)+PD detector can provide a very good energy resolution, $\Delta E(FWHM)/E < 2\%$, for heavy ions with intermediate energy.

The radiation hardness is an important parameter for crystal detector, especially for crystal EMC used in high energy physics experiments with high energy γ-ray radiation background[11, 12]. The systematical test of radiation hardness will be completed in the near future.

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