Nuclear Instruments and Methods in Physics Research A 786 (2015) 51–58

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Front-end electronics for CsI based charged particle array for the study of reaction dynamics

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ARTICLE INFO

Article history:
Received 8 August 2014
Received in revised form
18 February 2015
Accepted 1 March 2015
Available online 11 March 2015

Keywords:
CsI(TI)
Charge sensitive preamplifier
Pulse shape discrimination

ABSTRACT

The characteristics and performance of a new detector system based on CsI(TI) scintillators, and its front-end electronics are presented. The detector system has been developed for the detection of light charged particles to investigate fusion–fission dynamics, and will also serve as ancillary detector for an array of neutron detectors. CsI scintillators are read by photo-diodes. The main feature of the array is its compact and simple high density front-end electronics which includes custom developed low noise charge sensitive preamplifiers (with very low power consumption for operation inside vacuum), NIM differential drivers, and commercially available Mesytec amplifiers with two different time constants for particle identification using a ballistic deficit technique.

1. Introduction

The use of CsI(TI) detectors for the study of reaction dynamics is well established. The characteristics of heavy ion induced fusion and fusion–fission reactions around the Coulomb barrier can be investigated by the study of charged particle energy spectra, particularly the emission of light charged particles such as protons and alphas. Pre- and near-scission [1,2] charged-particle emission spectra and multiplicities provide important information on the statistical and dynamical aspects of the fusion–fission process and scission point characteristics of the fissioning nucleus, which is important to understand the collective fission dynamics. Measurement of alpha particle energy spectra and multiplicities in coincidence with fission fragments, at different relative angles, is a very important probe to understand fission dynamics. A detection system with high detection efficiency/large solid angle coverage and granularity, and with particle identification capability is required for such studies. At the same time, a competent and cost effective front-end electronics system is also required for the signal processing of these detectors. For large number of detectors, the front-end electronics should be high density with low power consumption. At the same time it should be modular, so that more number of detectors and its electronics can be added with ease as per the experimental requirements.

CsI scintillators read by photo-diodes are widely used for the detection of charged particles [1–4], gamma rays [5] and high energy photons [6] because of their compact size, low operating voltage and matched spectral response between scintillator and photo-diode (as compared to photomultiplier tubes) [7]. On the other hand, as described later in the text, custom designed front-end electronics are required for processing the weak signals from this detector, and to extract the identity of the incident particle. We have developed a detector system based on CsI(TI) scintillators coupled to photo-diodes along with its front-end electronics for performing experiments described above. The salient feature of the front-end electronics is that it is simple, compact, modular, easy to setup and is a combination of commercially available NIM and CAMAC units as well as custom units developed in-house. They comprise of custom developed charge sensitive preamplifiers (having low noise and low power consumption), NIM differential driver unit, and commercially available NIM Mesytec Amplifier units, and Phillips CAMAC ADC. The used Mesytec shaping amplifiers have two different shaping times for energy measurement and pulse shape discrimination, and modified time constants for timing discriminators compatible with CsI detector signals. The array can be used as stand alone or it can be used with other detectors such as gas proportional counters, ionization chambers,

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http://dx.doi.org/10.1016/j.nima.2015.03.005
0168-9002/

Silicon detectors etc. This will be used as an ancillary detector for the newly commissioned National Array of Neutron Detectors (NAND) [8]. The detectors have been thoroughly tested off-line with radioactive sources and have been used in experiment, using the beam from the IUAC tandem accelerator [9]. This article describes the above detector system and its front-end electronics in detail.

2. Detector system

The detector system described in this paper has been developed to investigate pre-, post-, and near-scission charged particle multiplicities in fission experiments. The reactions of interests are limited to near Coulomb barrier energies, therefore only light ions (such as protons and alphas) of low energies (2–30 MeV) need to be detected. Charge particle multiplicities in fission experiments are very low ($\sim$0.1). At the same time, the light charged particles emitted during the reaction need to be detected in coincidence with the fission fragments. Therefore it is required to have a large solid angle coverage by the detectors. In other words, detectors need to be mounted close to the target with sufficient granularity so as to extract angular distribution with respect to fission fragments. Since the detectors will be placed close to the target ($\sim$20 cm), they should have high count rate handling capability and at the same time should not be prone to radiation damage. The count rates due to elastic scattering of beam like particles can be as high as 3 kHz, depending upon the thickness of the target, polar angle of the detector (with respect to beam direction), and the beam intensity. The detector system should have particle identification capability so as to discriminate between different types of light particles such as protons, deuterons, tritons, alphas etc. The detector should have reasonably good energy resolution. Traditionally Silicon detectors have been the choice to perform such measurements. They have a very good energy resolution, they are available in segmented forms and particle identification can be done by using ΔE–E telescopes or pulse shape discrimination techniques. A major disadvantage of Silicon detectors is that they are very prone to radiation damage. As a result charge collection efficiency, and therefore signal amplitude, decreases as fluence increases during the experiment. CsI scintillator coupled to a photo-diode offer a very flexible and inexpensive solution for such applications. One of the main characteristics of CsI(TI) detectors is its intrinsic ability to discriminate between different light particles such as protons, alphas, electrons (gamma photons) etc. according to their stopping power. This is due to the different decay time constants in the light output for different particles. Using suitable pulse shape discrimination techniques, one can determine the identity of the particle. At the same time, they also have reasonably good energy resolution of about 200 keV for 5.48 MeV alpha which is good for studies described earlier. The detector system used in current set up has sixteen CsI(TI), each having an area of 20 mm $\times$ 20 mm with a thickness of 3 mm. This much of thickness is sufficient to stop protons up to 25 MeV, and alphas up to 100 MeV. The region of interest of alpha energy spectra, for the physics motive described above, lies from 4–30 MeV, and that for proton energy spectra is 2–20 MeV. The crystals are read by 10 mm $\times$ 10 mm photo-diode (Model no. S-3590-08 from Hamamatsu). The crystals are coupled to the photo-diode via square shaped (un-tapered) 20 mm $\times$ 20 mm $\times$ 7 mm thick Plexiglass light guide. The front surface of the crystal is covered with a 2 μm Mylar, Aluminized on both the sides. The assembled units, model no. V 20 PM 3/10-Cs, have been supplied by Scionix, the Netherlands [10]. The TI doping concentration is approximately 0.1 mol%.

3. Signal processing

3.1. Front-end electronics

High density and compact front-end electronics are required for the signal processing of large number of CsI(TI) detectors with pulse shape discrimination capabilities. There is no easy or viable solution for the same available commercially. CsI(TI) arrays such as Microball [3] and DIAMANT [4] have their own front-end electronics developed in-house which are not available commercially. The front-end electronics described in this article have been developed using commercially available high density NIM amplifier units, CAMAC ADC, and in-house developed charge sensitive preamplifiers (CSPA) and differential driver units.

Fig. 1 shows the schematic for the signal processing of CsI scintillation detectors with photo-diode readout. The light output from the CsI crystal is converted into an electrical signal by the Silicon photo-diode. The photo-diode is read by a conventional CSPA. This is followed by a buffer stage with differential outputs. This output is fed to two sets of multi-channel shaping amplifiers (with built in leading edge (LE) discriminator), one having a shaping time of 0.5 μs and other with 3 μs. Output from shaping amplifiers is fed to peak sensing analog to digital converters (ADC). The master gate for the ADC is provided by Gate and Delay generator (GDG) using strobe from the LE discriminator.

The charge generated by the photo-diode is very small due to small light output ($\sim$20 eV for generation of one light photon) from the CsI crystal per unit energy loss. Thus it is desirable for the CSPA to have low noise, high gain, good timing features (ability to distinguish between different decay times from CsI), and low power consumption so that it can be placed in vacuum

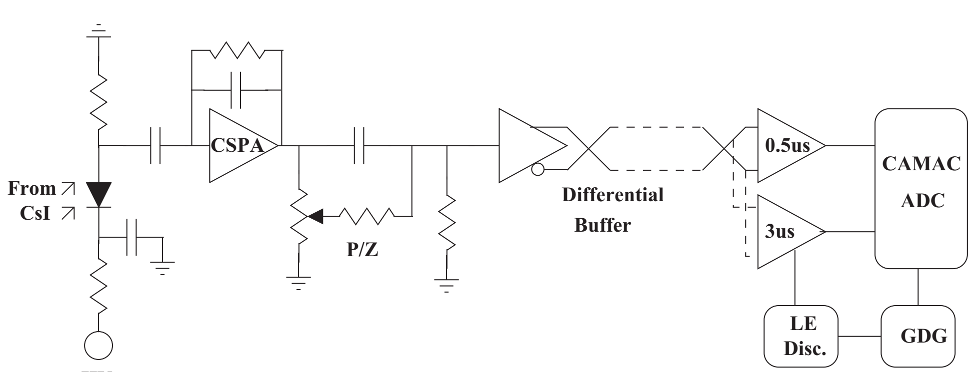

Fig. 1. Block diagram of the front-end electronics for the CsI detector. CSPA is the charge sensitive preamplifier, P/Z is the pole-zero cancellation network, 0.5 μs and 3 μs are shaping times of the two amplifiers used, LE is the leading edge discriminator and GDG is the gate and delay generator.