

Development of InP detector for $pp/{}^7\text{Be}$ solar neutrino measurement

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Abstract. A radiation detectors used a semi-insulating Indium Phosphide (InP) wafer for measurement of solar $pp/{}^7\text{Be}$ neutrinos have been developed in last a few years. A volume of the detector has achieved to 7mm^3 . This detector observed γ -rays, and measured a peak for the photoelectric effect at $-79\text{ }^\circ\text{C}$. The charge collection is mainly done by a carrier drift along to the electric field at outside of depletion layer, and the efficiency is achieved by 60 to 70%.

1. Introduction

In 2001, Super-Kamiokande [1] and Sudbery Neutrino Observatory [2] using the charged current process have established the ν_e oscillation in their solar neutrino measurement. KamLAND also confirmed the oscillation using a reactor $\bar{\nu}_e$ in sense of Δm^2 [3], however the mixing angle θ_{12} is still not restricted as well as θ_{23} observed in the atmospheric neutrinos. In order to obtain precise θ_{12} , it is necessary to measure not only the flux but also the spectral shape for solar $pp/{}^7\text{Be}$ neutrinos.

2. Solar $pp/{}^7\text{Be}$ neutrino experiment using ${}^{115}\text{In}$

Borexino has reported that the first detection of ${}^7\text{Be}$ neutrinos signal using low background liquid scintillator [4]. In 1976, R.Raghavan proposed the measurement of low energy solar $pp/{}^7\text{Be}$ neutrinos [5] via following reaction ${}^{115}\text{In} + \nu_e \rightarrow {}^{115}\text{Sn}^* + e^-$. The prompt electron has an energy with $E_\nu - 125\text{keV}$, here E_ν is an energy of incident neutrinos. Therefore the neutrino spectroscopy can be realized. An excited state of ${}^{115}\text{Sn}$ decays into the ground state with a lifetime of $4.7\text{ }\mu\text{s}$, and emits two gammas (116keV and 487keV). This signature is also able to use for a triple-coincidence to extract neutrino signal from huge backgrounds. However, ${}^{115}\text{In}$ itself has natural beta decay into the ground state of ${}^{115}\text{Sn}$ with a lifetime of 4.4×10^{12} years. The Bremsstrahlung could produce fake coincidence for neutrino signal. Therefore a fine segmented with well energy resolution detector is necessary [6].

3. InP solid state detector

Semi-insulating InP wafer is usually grown by the liquid encapsulated Czochralski (LEC). We have chosen another wafer produced by Sumitomo Electrical Industry Co. LTD with the method of Vapor Czochralski (VCZ). Hamamatsu Co. LTD developed InP detector with $10\text{mm} \times 10\text{mm}$ in surface, and 0.2mm in thickness. The electrodes consist of Cr-Au with $1\text{ }\mu\text{m}$ thickness for

top and Au-Ge/Ni/Au with 0.13/0.015/0.5 μm thickness for bottom. The junction between electrode and InP are ohmic contact in room temperature, however actually a Schottky barrier has been formed at $-79\text{ }^\circ\text{C}$ because of the rectification in the measurement of Hall effect.

4. Performance of InP detector

The performance of InP detector was measured by using gammas emitted by usual radio active sources. Carriers generated by the energy deposit of electrons via photoelectric process or Compton scattering are drifted along to electric field and reached the electrode. The expected charge could be evaluated by $Q[C] = \int_0^R \frac{dE/dx}{\epsilon} e^{-\frac{r(x)}{L_d}} dx \times e$. Here, L_d is carrier drift length, ϵ is an average energy for electron/hole pair production, R is electron range, and $r(x)$ is distance from electrode. Generally speaking, the carrier drift length is expressed by $L_d \equiv \mu\tau \frac{V_0}{d}$, here μ is the carrier mobility, τ is life-time of the carrier trapping. V_0 is the bias voltage, and d is thickness of the wafer. In the depletion layer, carrier life time is long enough to the drift time, so the observed charge should be same as $N_{eh} \times e$. For the measurements of gammas, the detector should be cooled by $-79\text{ }^\circ\text{C}$. using Dry-Ice. Figure.1 shows that the observed charge distribution. There found two peaks in each spectra. For instance, the peak for 122keV gamma-ray appears around $0.3 \times 10^{-14}\text{ C}$ and $0.55 \times 10^{-14}\text{ C}$. Higher charge peak is produced by the charge collection of depletion layer, and it is consistent with other gammas assuming by 3.5eV of an average energy for electron/hole pair production. This assumption is also confirmed the peak position was not changed as bias voltage increasing. On the other hands, lower charge peak moves to higher position rapidly. The collection efficiency for lower peak is obtained by the 56% in case of 122keV γ , and this peak was formed by charge collection due to carrier drift outside of the depletion layer. According to a simulation, the spectral shape could reproduce assuming both $L_d = 250\mu\text{m}$ and $20\mu\text{m}$ for the thickness of depletion layer as shown in Figure.1.

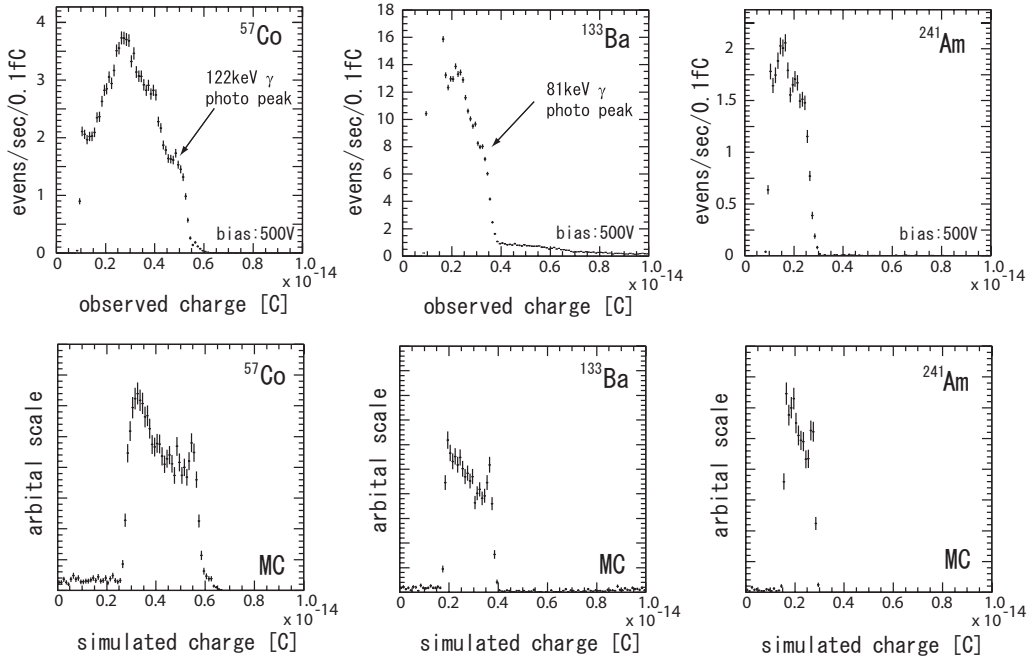


Figure 1. Observed and simulated charge distributions for gamma-rays are shown.

5. Conclusion

An InP detector has been developed, and obtained good performance. Observed charge spectra could be explained by carrier drift with $250\mu\text{m}$ and collection efficiency is achieved by 60 to 70 %. This is the first time to demonstrate InP detector with a bulk size crystal, and the detector performance shows us that it is possible to use for solar $pp/{}^7\text{Be}$ neutrino measurement.

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