

InP solid state detector for a measurement of low energy solar neutrinos

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Abstract. A large volume radiation detectors using a semi-insulating Indium Phosphide (InP) wafer have been developed for Indium Project on Neutrino Observation for Solar interior (IPNOS) experiment. The volume has achieved to $20mm^3$, and this is world largest size among InP detector observed γ s at one hundred keV region. Most of charge are induced by moving carriers, and the charge collection efficiency and the energy resolution are obtained by 60% and 25%, respectively. We measured actual backgrounds related to ^{115}In β decay, and no significant background was found.

1. Introduction

Super-Kamiokande and Sudbery Neutrino Observatory experiment has established ν_e oscillation in their solar neutrino data in 2001[1, 2], and a long way problem so called Solar Neutrino Problem in past 30 years was almost solved by the LMA oscillation. Independently, KamLAND experiment confirmed the oscillation using reactor $\bar{\nu}_e$ in sense of Δm^2 [4]. Next step of neutrino physics should measure both precise oscillation parameters and CP phase in the MNSP matrix elements. For the future solar neutrino experiment, a precise θ_{12} measurement with 1% accuracy will help the determination of θ_{13} [3] and the direct investigation of solar interior on the stellar evolution theory, respectively. In this point of view, new experiment Indium Project on Neutrino Observation for Solar interior (IPNOS) should measure full scale of energy spectrum of solar neutrinos including pp neutrinos.

2. Low energy solar neutrino experiment using ^{115}In

In 1976, R.Raghavan proposed new technique for the measurement of low energy pp/ ^7Be solar neutrinos [5] via following reaction;



The prompt electron has an energy with $E_\nu - 114$ keV, here E_ν is an energy of incident neutrinos. Therefore the spectroscopy will be realized in the solar neutrinos. An excited state of ^{115}Sn shown in Eq.(1) decays into the ground state with a lifetime of $4.76\mu\text{s}$, and emits two γ s (116 keV and 497 keV). This signature will be also able to use for a triple-coincidence to extract neutrino signal from huge backgrounds. However, ^{115}In itself has natural β decay into the ground state of ^{115}Sn with a lifetime of 4.4×10^{14} years and the end point energy is 499keV. The radiative

Bremsstrahlung could produce fake coincidence for the neutrino signal. In order to avoid these backgrounds, a fine segmented with well energy resolution detector is necessary [6].

We have chosen semi-insulating wafer produced by Sumitomo Electrical Industry Co. LTD with the method of Vapor pressure Controlled 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 $0.03 \sim 1.0\mu\text{m}$ thickness for top and Au-Ge/Ni/Au with $0.13/0.015/0.5\mu\text{m}$ 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.

3. 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. The expected charge could be evaluated by Hecht formula; $Q[C] = Q_0\left\{\frac{L_e}{d}\left(1 - e^{-\frac{x}{L_e}}\right) + \frac{L_h}{d}\left(1 - e^{-\frac{d-x}{L_h}}\right)\right\}$ Here, $L_{e,h}$ is drift length of electron/hole, d is thickness of the detector, and x is distance from the electrode. Generally speaking, the carrier drift length is expressed by $L_{e,h} \equiv \mu_{e,h}\tau_{e,h}\frac{V_0}{d}$, here $\mu_{e,h}$ is the carrier mobility and $\tau_{e,h}$ is life-time of the carrier trapping for electron/hole, and V_0 is the bias voltage.

Figure.1 shows that the observed charge distribution. There found two peaks in each spectra. For instance, the peak for 122keV γ -ray in ^{57}Co appears around $0.3 \times 10^{-14}\text{ C}$ and $0.55 \times 10^{-14}\text{ C}$. Higher peak is produced by full carrier collection due to reach the electrode, and it is consistent with other γ s assuming by 3.5eV of an average energy for electron/hole pair production. The collection efficiency for lower peak is obtained by the 60% in case of 122keV γ s, and this peak was formed by the induced charge as explained by Hecht formula. According to a simulation, the spectral shape could be reproduced assuming both $L_e = 200\mu\text{m}$ and $L_h = 30\mu\text{m}$ as shown in bottom of Figure.1.

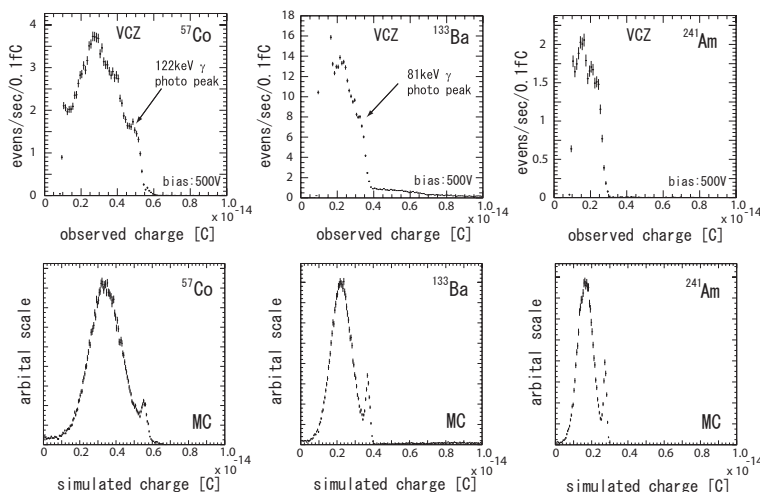


Figure 1. Observed and simulated charge distributions for gamma-rays are shown.

4. Measurement of backgrounds

As described in section 2, ^{115}In decays naturally with β emission, and the radiative Bremsstrahlung due to ^{115}In nuclei might be possible background in the observation of solar neutrinos. For the measurement of those effect, we used InP detector for measurement of β

event and CsI(Tl) scintillator for the measurement of radiative Bremsstrahlung. The CsI size was $50\text{mm} \times 50\text{mm} \times 20\text{mm}$. These two detectors are located by face to face and set inside of radio-active shield which consist of the lead in 5cm thickness and the oxygen free copper in 1cm thickness. The $4\text{-}\pi$ active veto plastic counter surrounded the shield was used for rejection of cosmic-ray backgrounds. The energy threshold for InP and CsI detector was 100keV and 50keV, respectively.

In order to detect the radiative Bremsstrahlung, we took coincidence between InP and CsI detector within $10 \mu\text{sec}$. In case of 17.3 hours measurement, 46 events were observed. Before concerning of the coincidence events, it is necessary to take into account U/Th natural backgrounds. According to measurement of U/Th activity using ultra-low background germanium detector located in Kamioka mine, the InP wafer contains them as order of 10^{-11}g/g . Also right figure of Fig.2 shows the energy spectrum of CsI detector obtained by self trigger. It is clearly seen that the photo-electric peak due to some nuclei in the U/Th decay chain such as ^{214}Bi . The amount corresponds to order of 10^{-10}g/g in the CsI scintillator or surrounded material. According to left of Fig.2, most of coincidence events between InP and CsI detector

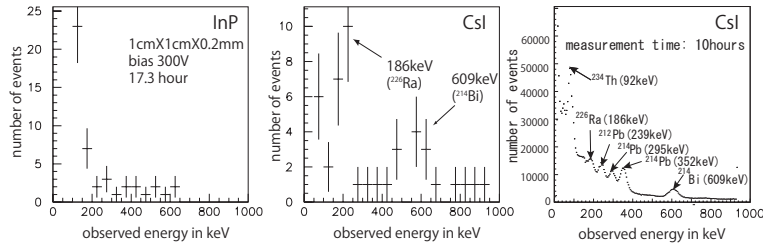


Figure 2. Energy spectrum of coincidence events for CsI and InP detector for 17 hour data, and U/Th background observed in CsI detector by self trigger.

looks consistent with $\beta\text{-}\gamma$ coincidence of U/Th backgrounds in those detectors as indicated by ^{214}Bi γ observed in CsI, and no clear evidence for the effect of radiative Bremsstrahlung was found. An accidental triple coincidence between InP detector and the scintillator should be evaluated by $5 \times 10^{-6}\text{events/day/unit detector}$, which corresponds to 10 events/day/4ton detector in case of IPNOS detector. Therefore, we have to reduce the amount of U/Th contamination order of 0.1, however it is not so hard to control the production of materials.

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%. No clear evidence of radiative Bremsstrahlung was found.

Acknowledgments

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References

- [1] Super-Kamiokande collaboration, Phys.Rev.Lett. **86** (2001) 5651.
- [2] SNO Collaboration, Phys.Rev.Lett. **87** (2001) 071301.
- [3] G.L.Fogli, E.Lisi, A.Marrone, A.Palazzo and A.M.Rotunno, Phys.Rev.Lett. **110** (2008) 141801
- [4] KamLAND collaboration, Phys.Rev.Lett. **90** (2003) 021802.
- [5] R.S.Raghavan, Phys. Rev. Lett. **37** (1976) 259.
- [6] R.S.Raghavan, hep-ex/0106054.