Development of InP solid state detector and liquid scintillator containing metal complex for measurement of pp/^{7}Be solar neutrinos and neutrinoless double beta decay

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Abstract. A large volume solid state detector using a semi-insulating Indium Phosphide (InP) wafer have been developed for measurement of pp/^{7}Be solar neutrinos. Basic performance such as the charge collection efficiency and the energy resolution were measured by 60% and 20%, respectively. In order to detect two gammas (115keV and 497keV) from neutrino capture, we have designed hybrid detector which consist InP detector and liquid xenon scintillator for IPNOS experiment. New InP detector with thin electrode (Cr 50Å- Au 50Å). For another possibility, an organic liquid scintillator containing indium complex and zirconium complex were studied for a measurement of low energy solar neutrinos and neutrinosless double beta decay, respectively. Benzonitrile was chosen as a solvent because of good solubility for the quinolinolato complexes (2 wt%) and of good light yield for the scintillation induced by gamma-ray irradiation. The photo-luminescence emission spectra of InQ_3 and ZrQ_4 in benzonitrile was measured and liquid scintillator cocktail using InQ_3 and ZrQ_4 (50mg) in benzonitrile solutions (20 mL) with secondary scintillators with PPO (100mg) and POPOP (10mg) was made. The energy spectra of incident gammas were measured, and they are first results of the gamma-ray energy spectra using luminescent of metal complexes.

1. Introduction

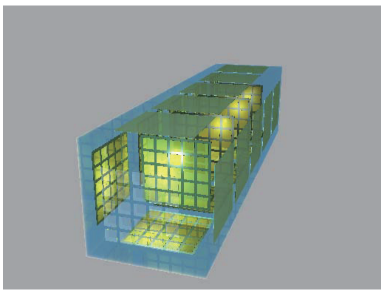
Super-Kamiokande and Sudbery Neutrino Observatory experiment has established ν_e oscillation in their solar neutrino data in 2001[1, 2], and a long way problem so called Solar Neutrino Problem in past 30 years was almost solved by the LMA oscillation. Independently, KamLAND experiment confirmed the oscillation using reactor $\overline{\nu_e}$ in sense of Δm^2 [3]. 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} [4] 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) would measure full scale of energy spectrum of solar neutrinos including pp neutrinos.

On the other hands, ^{96}Zr is one of the expected nuclei for neutrinoless double beta decay with higher Q-value (3.72MeV). In order to avoid gammas from ^{208}Tl decay, it is better to have high Q-value than 2.6MeV. Several experiments are planned such as COBRA which used CaZnTe solid state detector and Super-NEMO with Mo and Se. Generally speaking, those experiments use target nuclei with order of 100kg, however we need ton-scale target nuclei to reach 0.1eV order for the neutrino mass. In this point of view, a large target ($\geq$ 500kg) experiment such as SNO+ (^{150}Nd) and KamLAND-Zen (^{136}Xe) should have a possibility to observe neutrinoless double beta decay events. In order to realize ton-scale target experiment, we have chosen ^{96}Zr and developed the Zr complex which could be solved at order of 10% in the organic scintillator.

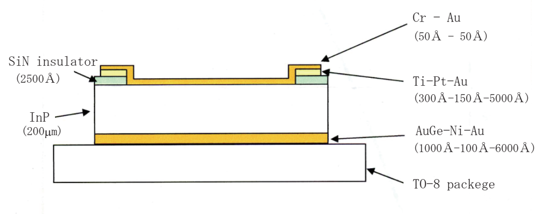
2. InP detector with thin electrode

We have chosen semi-insulating wafer produced by Sumitomo Electrical Industry Co. LTD with the method of Vapor pressure Controlled Czochralski (VCZ) and the vertical bridge (VB). Hamamatsu Co. LTD developed InP detector with $6mm \times 6mm$ in surface, and $0.2mm$ in thickness. The performance of InP detector was measured by using gammas emitted by usual radio active sources and no background from the radiative Bremsstrahlung was found [6]. The average energy for electron/hole pair production is 3.5eV, and the charge collection efficiency is obtained by 60%, and the energy resolution is almost 20% at 122keV.

Recently we had new idea to observed the scintillation light due to delayed gammas. The IPNOS detector was designed by InP detector for observing the prompt electron emitted by neutrino capture, and also observing scintillation lights emitted by liquid xenon scintillator surrounded by the InP detector. The conceptional detector design is illustrated by Fig.1 (a). The InP detector was located at the wall which is filled with liquid xenon. In order to observe the scintillation light from liquid xenon, top electrode should be formed with thin layer as illustrated in Fig.1(b). The thickness of electrode is formed with Cr 50 Åand Au 50Å.



(a) IPNOS



(b) InP

Figure 1. (a) Conceptional design for IPNOS experiment.(b) InP detector with thin electrode (Cr 50Å- Au 50Å) to observe scintillation light from liquid xenon.

3. InQ_3 and ZrQ_4 loaded liquid scintillator

A liquid scintillator solved indium was developed by Suzuki et al[7] and LENS project [8]. Recently LENS group presented the feasibility of realistic way for a proto-type detector (Mini-

LENS) [9], which will use MVA indium complex in the Liner Arkyl Benzen (LAB) [10].

We had a new idea to observe such a low energy solar neutrinos and also neutrinoless double beta decay using liquid scintillator. Metal complex usually has large solubility for the organic solvent, and some complexes also have a luminescence, so that it could be role as secondary scintillator. We have chosen A tris (8-quinolinolato) indium (InQ_3) and a tetrakis (8-quinolinolato) zirconium (ZrQ_4) as such complex. These are not commercially produced, so we have to synthesize using metal salt compound and quinolinolato regands.

We have searched for an organic solvent which should have high solubility of InQ_3 and ZrQ_4 complex, and have found benzonitrile (C6H5CN: PhCN) which has an order of a few % solution. The maximum photo luminescent wavelength of PhCN is 291nm, a flash point is 75 °C, and the attenuation length is 66cm for the 0.5wt% dissolution.

Maximum emission wavelength of InQ_3 and ZrQ_3 are found at 559.3nm (excitation wavelength : 397nm) and 548.0nm (excitation wavelength : 387nm), respectively. The absorption of InQ_3 and ZrQ_4 complex also measured by the spectrophotometer. The maximum absorption wavelength were located at 394.7nm for InQ_3 and 383.3nm for ZrQ_4 complex, respectively. The obtained quantum yield were also measured by using standard material, and obtained by 0.050 and 0.011 for InQ_3 and ZrQ_4, respectively.

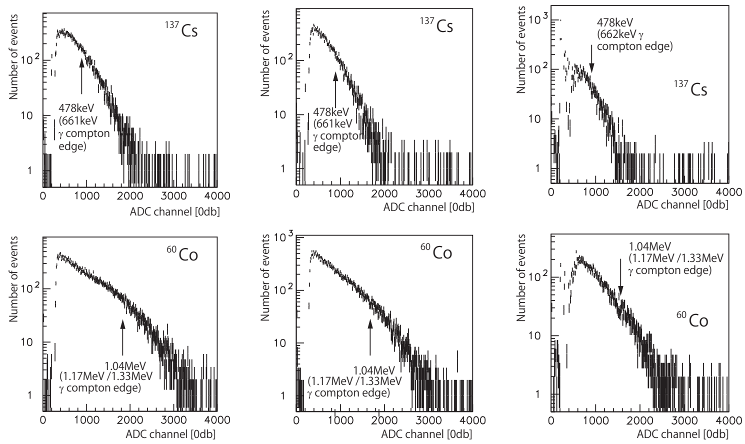
4. Performance of liquid scintillator containing metal complex

For the measurement of performance, we used gammas from ^{137}Cs (662keV) and ^{60}Co (1.17MeV and 1.33MeV). Usual gammas interact with electrons in liquid scintillator, and emit an electron via photo-electric effect or Compton scattering. In order to transfer the energy deposited by electron to the photomultiplier, we resolved 2,5-Diphenyloxazole (PPO) which has absorption maximum at 309.7nm and fluorescence maximum at 368.0nm in PhCN. In addition, 1,4-Bis(5-phenyloxazol-2-yl)benzene (POPOP) would help the energy transfer due to overlap between the emission of POPOP and the absorption of InQ_3 and ZrQ_4.

The liquid scintillator was put into 20mL quartz vials, and two 2-inch photomultiplier (Hamamatsu H6410) are connected to the vial through acrylic light guide for the coincidence method for avoiding backgrounds. Comparing of light yields, PhCN with PPO 100mg and POPOP 10mg cocktail scintillator has 63% relative to the standard liquid scintillator (BC505). Here, the wavelength of emitted lights for both scintillators are almost same ($\sim$ 420nm). The quantum efficiency of Hamamatsu H6410 photomultiplier is 25% at 420nm.

We measured the energy spectrum of induced gamma-ray from radio isotopes using 50mg of InQ_3 and ZrQ_4 solved in PhCN with PPO 100mg and POPOP 10mg as shown in Fig.2 (a) and (b). The scintillation light yield of ZrQ_4 looks smaller than that of InQ_3. This should be explained by the difference of quantum yield of those complexes. The quantum yield of quinolinolato complex could be evaluated by difference of scintillation photon yield between the only PhCN cocktail scintillator and PhCN cocktail scintillator containing complex. Because of different wavelength of those scintillator, we have to correct the light yield by the quantum efficiency of H6410 photomultiplier. The emission wavelength of InQ_3 and ZrQ_4 in PhCN is 559nm and 548nm, respectively. The quantum efficiency of PMT is obtained by 12.6% and 9.3%, respectively. Therefore, the quantum yield of InQ_3 and ZrQ_4 dissolved in PhCN cocktail scintillator are obtained by 15.6% and 11.5%, respectively. These values are larger than the value obtained by the photo luminescence.

This reason was explained by following. The photon emission from POPOP has slightly longer tail than the absorption distribution of InQ_3 and ZrQ_4 complex. This means that the residual photon could be contaminated in the emission of InQ_3 and ZrQ_4 complex. In order to evaluate the amount of POPOP residual light, we measured the emission of scintillation light from InQ_3 dissolved in PhCN cocktail scintillator via the sharp cut filter (FujiFuilm : SC-48). This film has transparency of 92% above 530nm and quickly decrease the efficiency below 530nm



(a) InQ_3 50mg (b) ZrQ_4 50mg (c) InQ_3 50mg via SC-48 filter

Figure 2. Observed energy spectrum of (a) InQ_3 50mg (b) ZrQ_4 50mg and (c) InQ_3 50mg vi SC-48 filter dissolved in PhCN cocktail scintillator for ^{136}Cs (top) and ^{60}Co (bottom).

(50% at 482nm and 10% at 470nm). The observed energy spectrum of InQ_3 dissolved in PhCN cocktail scintillator showed that the photon light yield was lost about 34% as shown in Fig.2(c). On the other hands, 23% of the light yield of PhCN cocktail scintillator still remained even via SC-48 filter. Therefore the difference of quantum yield between the photo luminescence and the gamma irradiation could be explained by the residual light from POPOP, and the amount of those are expected by 10% at maximum.

5. Conclusion

An InP detector with thin electrode (Cr 50Å- Au 50Å) has been developed, and an organic liquid scintillator containing InQ_3 and ZrQ_4 complex was demonstrated. We need quinolinolato complex with new substitution group which will improve the quantum yield to be 0.533, and the maximum emission wavelength to be shifted at 490nm [11].

Acknowledgments

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