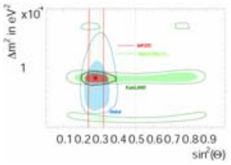
InP solid state detector for measurement of low energy solar neutrinos (Indium Project on Neutrino Observation for Solar interior : IPNOS)

Y.Fukuda[a] T.Izawa[d] Y.Koshino[b] S.Moriyama[b] T.Namba[c] M.Shiozawa[b]

[a] Miyagi University of Education [b] ICRR, University of Tokyo [c] ICEPP, University of Tokyo [d] Solid state division, Hamamatsu Photonics K.K.

1. Introduction

◆ Purpose (1) Determine ν oscillation mixing angle θ_{12}



・96%C.L. allowed region obtained by global fit

LMA solution (blue) : Cl + Ga + SK (D/N spectrum)

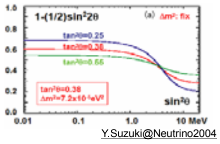
KamLAND (green) → confirm Δm_{12}^2

$27^\circ < \theta_{12} < 37^\circ$

・mixing angle θ_{12} is not fixed compared with θ_{23} (obtained by Atm. ν)

・Survival probability would increase at 5MeV or less in case of LMA solution, and the shapes depends on the value of θ_{12}.

pp/^{7}Be solar neutrino spectrum will fix precise θ_{12}.



Y.Suzuki@Neutrino2004

● **on-going solar pp/^{7}Be experiment**
- KamLAND (Liquid scintillator, electron elastic scattering [ES])
- Borexino (Liquid scintillator, ES)

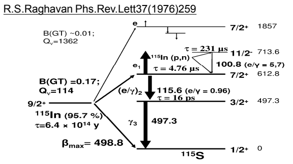
● **future solar pp/^{7}Be experiment**
- XMASS (LXe, ES, DARK MATTER)
- LENS (Liquid scintillator loaded In/Ye, charged current [CC])
- CLEAN (LNe, ES)
- MOON (^{100}Mo,CC)
- SIREN (^{160}Gd, CC)

◆ Purpose (2) Solve new solar problem

small descrepancy between observation of Helioseismology and prediction of standard solar model will be solved by CNO cycle ⇨ only neutrinos from CNO cycle tells us definite answer

◆ Technique of low energy solar neutrino detection

R.S.Raghavan Phs.Rev.Lett37(1976)259



$^{115}In + \nu_e \rightarrow {}^{115}Sn^* + e^-$

$^{115}Sn^*(4.76\mu s) \rightarrow {}^{115}Sn + \gamma_1(115keV) + \gamma_2(497keV)$

● **Advantage**
- large cross section (~640SNU)
- direct counting for solar neutrinos
- sensitive to low energy region ($E_\nu \geqq 125keV$)
- energy measurement ($E_e = E_\nu - 125keV$)
- triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)

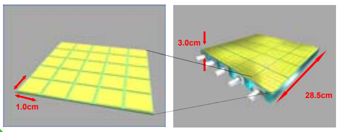
● **Disadvantage**
- natural β-decay of ^{115}In ($\tau_{1/2} = 4.4 \times 10^{14}$ yr , Ee≧498keV)
- possible BG due to correlated accidental coincidence by radiative Bremsstrahlung

◆Possible detector with 4tons of ^{115}In assuming 5 years operation

- Number of expected events assuming no ν oscillation → 1885
- Number of expected event assuming LMA solution with Ee≧100keV → 720

Statistical and theoretical error in total → ~3.5 % ⇨ **$\theta_{12} = 30^\circ - 34^\circ$**

◆InP solid state detector (as both target and detector) with scintillator



●**Hybrid structure of InP and solid scintillator**
- InP multi-pixel detector (10mmX10mmX0.2mm cell)
- solid scintillator surrounding InP detector to detect γs

●**4tons of ^{115}In detector for solar ν experiment**

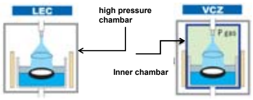
InP : 5.1tons (2.0X10^6 modules with $\Delta E/E$~10%)

solid scintillator (ex. CsI) : 934tons

total size : 6.3m X 6.3m X 5.3m

2. Semi-Insulating(SI) InP semi-conductor

● **VCZ (Vapor Pressure Controlled Czochralski)**



http://www.sei.co.jp/sc/technical/inp.html

・**Product : Sumitomo Electric Industries, Ltd.**

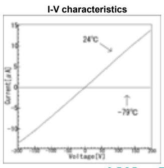
・**Process**

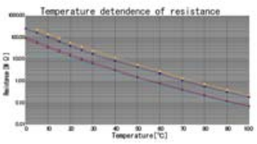
In inner chamber controlled by steam pressure of As or P, covering material melt by B_2O_3 like LEC method and pulling up single crystal growth from it. Because of crystal growth in low temperature gradient, transition density can reduce.

● **Characteristic table**

EPD	~5,000cm^{-2}
Conduct	Semi-insulation
Dopant	InP(Fe)
Resistivity	(4.9~5.2)×10^{7}Ωcm
Mobility	(2.8~2.7)×10^{3}cm^{2}V^{-1}s^{-1}
Thickness	456~459μm
Diameter	50.00mm
Orientation	(100)±0.03°

I-V characteristics





$I [A] \propto T^{2/3} \exp(-E_g/2k_BT)$

E_g : band gap (1.29eV)

k_B : Boltzmann constant

T : element temperature

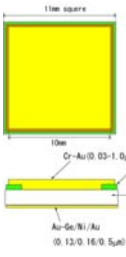
Dark current could be reduced by lowering temperature

3. SI InP cell detector

●**InP detector in vacuum dewar**

cooled by Dry-Ice (-79 ℃) or LN2 (-185 ℃)

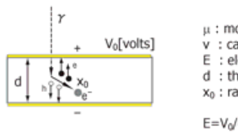
Schematic view of InP detector



Size:
10mm×10mm×0.2mm

Electrode :
- Ohmic contact
- Au vacuum evaporation
- Insulator (SiN) to avoid leak current

●**Charge collection scheme**



μ : mobility [m^{2}V^{-1}s^{-1}]

v : carrier velocity [ms^{-1}]

E : electric field [vm^{-1}]

d : thickness of SI InP

x_0 : range of electron

$E=V_0/d$ $v=\mu E=\mu V_0/d$

drift length : $L_d=\tau v=\mu\tau V_0/d$ τ : carrier lifetime [s]

e/h creatrion energy : ε_{eh}

induced charge: $Q_{induced}$[C]=const.×(electron energy)/ε_{eh}×e×L_d

full Q collection: Q_{full}[C]= (electron energy)/ε_{eh}×e

Procedure to detect charge

1) Produced electron loses its energy, and creates electron-hole pair as carrier.

2) Carrier moves along electric field.

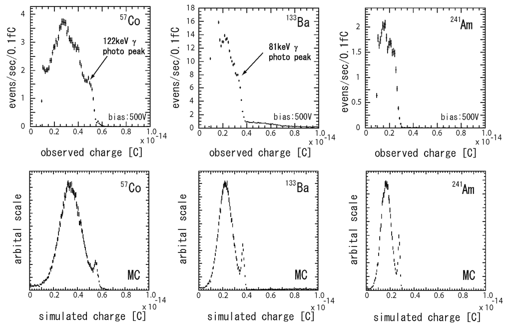
3) If drift length is enough to detector thickness, the charge collection efficiency achieves 100% as usual SSD.

4) If the drift length is not enough, the carrier might be trapped by the impurity before achieving the electrodes.

5) In above case, most collection done by induced charge.

4.Response for γ-rays

● **γ spectrum measurend by InP detector @-79 ℃**



- Measured clear photo-peak, but two peak structure
- Lower peak: induced charge (L_d~120mm)

Higher peak: full Q collection
- Energy of electron-hole pair production : 3.5eV

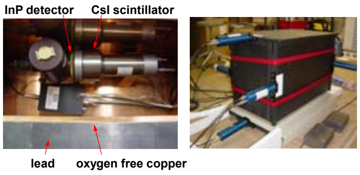
Energy resolution : 25%@122keV

InP detector works as expected, but less energy resolution

5. Background measurement

◆ Measurement the natural β decay of ^{115}In and demonstration for the triple fold coincidence

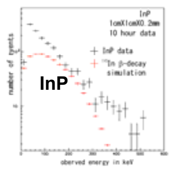
●Configuration of InP detector and CsI scintillator



- CsI(Tl) scintillator : to detect Bremsstrahlung and other coincidence events with InP detector
- CsI crystal size : 50mm×50mm×20mm
- radiation shield : lead in 5cm thickness and oxygen free copper in 1cm thickness
- 4-π active veto plastic counter : to veto cosmic ray muon

●Measure the β-decay spectrum in InP detector

・**Observed b-decay specrum**

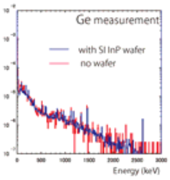


Observed spectrum has different shape from the one expected by β decay of ^{115}In

⇩

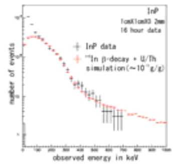
Events with E<100keV seem to be vibration noise

・**U/Th contamination in SI InP wafer**



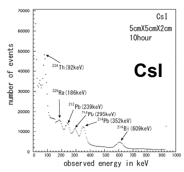
According to Ge measurement, amount of U/Th are estimated by 5X10^{-11} g/g and 3X10^{-11}g/g, respectively .

・**Observed events above 300keV**



Whole shape is consistent with ^{115}In + U/Th β–decay

●Measure the BG spectrum in CsI scintillator



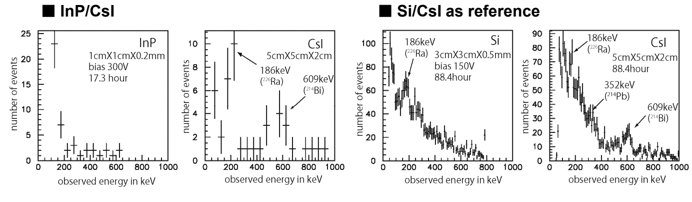
Several peaks of γ rays caused by U/Th contamination were observed in self trigger

⇩

amount of U/Th contamination was evaluated by ~10^{-10}g/g

●Coincidence BG events between InP (Si) detector and CsI scintillator

■ **InP/CsI** ■ **Si/CsI as reference**



- Observed spectrum by CsI scintillator are consistent with the U/Th γ (not inside of CsI)
- Observed spectrum by InP(Si) are expected by U/Th β–decay (inside and outside of InP(Si))
- No clear evidence for radiative Bremsstrahlung

●Effect of triple fold coincidence for detecting solar neutrinos

Assuming accidental triple coincidence in InP hybrid detector (ev#1) and solid scintillator (ev#2 with E~116keV and ev#3 with E~497keV) within 10μs gate width, 5×10^{-6} events/day/1 hybrid detector = 10 events /day/whole detector (2.0X10^6) is evaluated (S/N~0.2)

⇩

Amount of U/Th contamination in material should be reduced by order of 1/10)

6. Next step

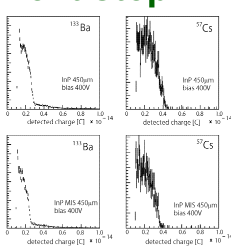
● **Improve energy resolution**

・reduce dark current

Metal-Insulator-Semiconductor (MIS) structure

・Increase drift length

improve quality and reduce impurity using wafer produced by Vertical Bridge method



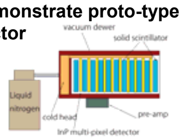
Thicker detector (0.5μm) reproduces the spectral shape with corresponding electric field.

MIS structure detector collect same amount of charge as usual detector.

⇩

Confirm induced charge , but same energy resolution

●**demonstrate proto-type detector**



We will test 1st proto-type detector (~100g InP) in 2009 and start mini-exp. (~10kg) in 2011