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

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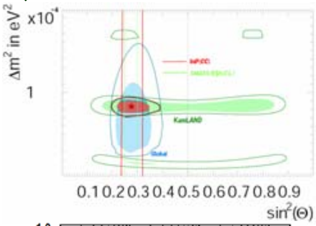
1. Introduction

◆ Purpose : Precise measurement of ν oscillation mixing angle θ_{12}

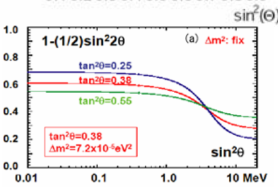
◆ Status of determination for ν oscillation parameter



・96%C.L. allowed region obtained by global fit
LMA solution (blue) : Cl + Ga + SK (D/N spectrum)
KamLAND (green) → confirm Δm_{12}^2

$27° < \theta_{12} < 37°$

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



Y.Suzuki@Neutrino2004

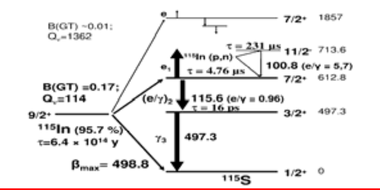
Survival probability tends to increase in 5MeV or less in case of LMA solution, and shapes depend on θ_{12}.

Amount of pp/^{7}Be ν should be observed

● future solar pp/^{7}Be experiment
・XMASS (LXe, elastic scatter(ES), DIRK MATTER)
・LENS (Liquid scintillator loaded In/Ye, charged current(CC))
・CLEAN (LNe, ES)
・MOON (^{100}Mo,CC)
・SIREN (^{160}Gd, CC)

◆ Technique of low energy solar neutrino detection

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



^{115}In + ν_e → ^{115}Sn* + e$^-$
^{115}Sn*(4.76μs) → ^{115}Sn + γ_1(115keV) + γ_2(497keV)

● **Advantage**
・direct counting
・sensitive to low energy ν(E_ν ≧ 125keV)
・energy measurable (E_e = E_ν − 125keV)
・Triple fold coincidence to extract neutrino signal (e_1 +γ_2 + γ_3)

● **Disadvantage**
・natural β-decay of ^{115}In ($\tau_{1/2}$ = 6.4 × 10^{14} yr)
・BG due to correlated accidental coincidence by Bremsstrahlung

●**Assuming observant of the 4tons of ^{115}In in 5 years**

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

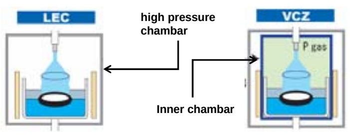
Statistical error and SSM theoretical error in total error → 3.9 % ⟶ θ_{12} = 29° - 34°

●**We will use Semi-Insulating(SI) InP semi-conductor as both target and detector**

2. Semi-Insulating InP semi-conductor

◆ InP crystal growth method

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



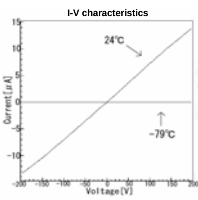
http://www.sei.co.jp/sc/technical/inp.html

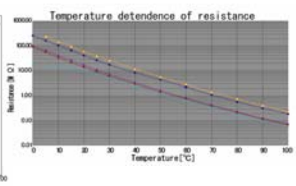
・**Product**
Sumitomo Electric Industries, Ltd.
・Process
In inner chambar controlled by steam pressure of As or P, covering material melt by B_2O_3 like LEC method and pulling up single crystal growth from it. Because of crystal growth in low temperature gradient, transition density can reduce.

● **Characteristic table**

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

I-V characteristics



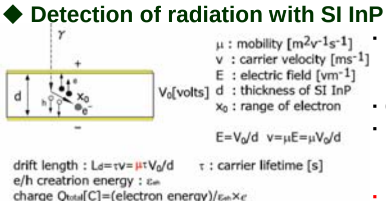


I [A] ∝ $T^{2/3}$ exp($-E_g/2k_BT$)
E_g : band gap (1.29eV)
k_B: Boltzmann constant
T : element temperature

Dark current could be reduced by lowering temperature

3. Test Module with the SI InP

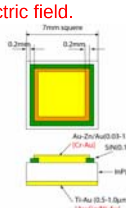
◆ Detection of radiation with SI InP solid state detector



charge Q_{total}[C]=(electron energy)/ε_{eh}×e
L_d≒∞ Q_{obs}[C]= $\int_0^R$(dE/dx)/ε_{eh} $e^{-(x/L_d)}$ dx ×e

・Electron produced by radiation loses the energy, and produce electron-hole pair as carrier.
・Carrier moves along electric field.
・If drift length is not enough to the thickness of detector, the carrier might be trapped by impurity before reaching electrode.
・Drift length is proportional to carrier mobility and electric field.

●**InP detector with cooling dewar**

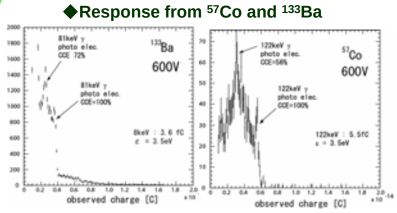


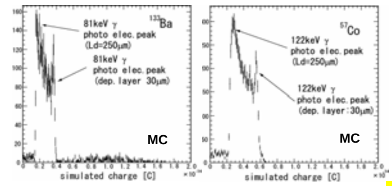
Size:
7mm×7mm×0.2mm
Electrode :
・Ohmic contact
・Vacuum evaporation of Au base

Schematic view of InP detector

4. Response for γ-rays

◆**Response from ^{57}Co and ^{133}Ba**

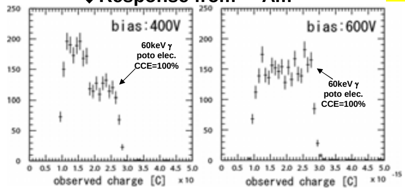




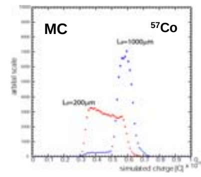
γ spectrum obtained by InP detector
・Photo electric peak for 81keV (^{133}Ba) and 122keV (^{57}Co) were observed,
・However, two peaks were found.
・Higher peak corresponds to photo electric peak with charge collection efficiency (CCE) 100%.
・Average energy of electron/hole pair production is obtained by 3.5eV.
・Lower peak is equivalent to CCE 56%(^{57}Co) and 72%(^{133}Ba), respectively.
・Energy resolution σ=5%@122keV

Spectral analysis with MC
・Assuming depletion layer formed at the ohrmic contact of electrode and carrier drift in remaining part.
・Input parameter : depletion layer =30μm L_d=250μm, ε=3.5eV
・MC reproduces spectral shape of data.

◆**Response from ^{241}Am**



Carrier drift length L_d is not enough



Low CCE signal improved by applying higher bias voltage

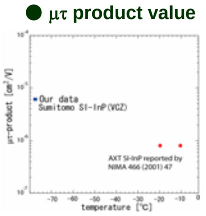
⟹ **increase carrier drift length (Ld)**

Assuming Ld ~1000mm, spectrum is single peak with good E resolution

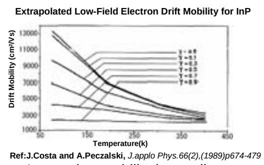
◆ How to increase the carrier drift length

1. Increasing mobility (μ) | **Temperature ⟶ lower**

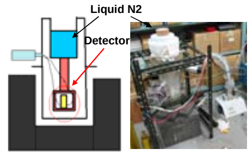
● **μτ product value**



・Increasing μτ product value at lower temperature



Ref:J.Costa and A.Peczalski, J.applo Phys.66(2),(1989)p674-479
・Increasing mobility by cooling



Cryostat for LN2 in preparation

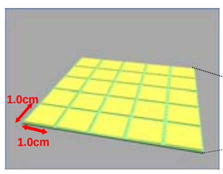
Dry ice (-79 ℃) ⟶ Liquid N_2(- 186℃)

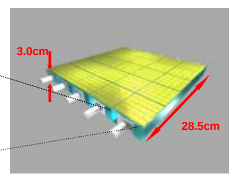
Direct measurement for mobility using Hall Effect Measurement System will be done at this summer

2. Higher bias voltage (V_0) | **Change electrode material (Au ⟶ Pd, Ag)**

・Avoid electric noise due to dark current
・Shottky barrier height: 0.37eV(Au) / 0.41eV(Pd) / 0.54eV(Ag) Ref: J.Phys.III 1(1991) 749-758

5. Development of InP prototype detector for solar neutrino experiment

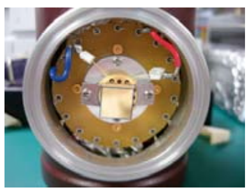


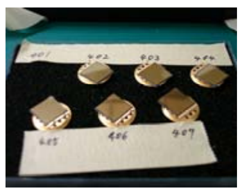


●**Hybrid structure of InP and CsI crystal scintillator**
・InP detector module 10mmX10mmX200μm detectors in 5x5 pixel
・CsI crystal scintillator to detect γs 3cmX5cmX28.5cm

●**4tons of ^{115}In for solar ν experiment**
InP=5.1tons (2.1X10^6 modules)
CsI=934tons
size : 6.3m X 6.3m X 5.3m

◆ New test module for prototype detector

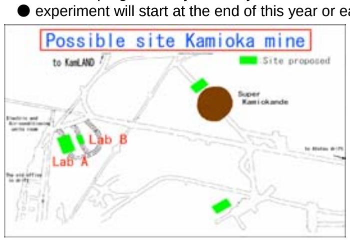




● **Actual module for proto- type detector**
・10mm X 10mm X 0.2mm
・delivered from 12th of July !
・first data has been taken and observed same spectrum
・proto-type detector consists of 4 modules

◆ ^{115}In β-decay spectrum and bremsstrahlung Background measurement at Kamioka mine

● estimate effect of accidental coincidence due to backgrounds.
● establish counting methods.
● scientific program in Kyoudou-riyou of ICRR, Univ. of Tokyo
● experiment will start at the end of this year or early of next year



Schematic view of experimental setup