Radiopurity studies of indium-doped tin alloys for TIN.TIN

A. Mazumdar[1,2],* G. Gupta[3], J. Raval[4], A. Garai[1,2], H. Krishnamoorthy [1,2], V. Nanal[3], R.G. Pillay[3], A. Shrivastava[2,5], A. Thamizhavel[6], and R. Mondal[6]
[1] *INO, Tata Institute of Fundamental Research, Mumbai - 400005*
[2] *Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094*
[3] *DNAP, Tata Institute of Fundamental Research, Mumbai - 400005*
[4] *Department of Physics, Vellore Institute of Technology, Vellore - 632014*
[5] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085 and*
[6] *DCMP&MS, Tata Institute of Fundamental Research, Mumbai - 400005*

Introduction

Search for neutrinoless double beta decay (NDBD) has attracted much attention in recent times, as it provides a unique means to probe the nature of neutrino - Majorana or Dirac. In India, development of cryogenic tin bolometer has been initiated to study NDBD in ^{124}Sn [1, 2]. Tin becomes superconducting at 3.7 K and at T<100 mK tin bolometer with excellent energy resolution can be made. However, tin undergoes an allotropic phase transition from a metallic beta phase to a semiconducting alpha phase at 13°C. This phase transition, commonly referred to as tin pest, is associated with a 27% increase in volume leading to the rupture of the sample [3]. This can affect the longevity as well as performance of the detector and hence poses a challenge. It has been reported that the allotropic transition can be suppressed by appropriately alloying the tin with certain elements. The choice for alloying element is constrained by its influence on the superconductivity of tin and its radiopurity. Radiopurity of the alloy is crucial as background minimization is critical for NDBD. Possible candidates for alloying are indium, cadmium and lead since they have good solid solubility in tin and are superconducting. However, the radiopurity of the alloys needs to be studied. With this motivation, tin crystals doped with indium were grown and characterized. This paper reports the radiopurity measurements of the indium-doped tin crystals using TiLES.

*Electronic address: `mazumdar.aparajita@gmail.com`

Experimental details and data analysis

Two crystals of Sn-In alloy were grown at TIFR with 7N purity tin and 6N purity indium, where the indium concentration was taken to be 0.5% and 16% (atomic %). The extreme concentration was chosen from the adopted Sn-In phase diagram at which the alpha phase is expected to be fully suppressed. The tin crystal doped with 0.5% In ($Sn_{0.995}In_{0.005}$) was grown using the modified Bridgman technique by carefully cooling the melt at 1°C/hr. The tin crystal doped with 16% In ($Sn_{0.84}In_{0.16}$) was grown in a Vertical Bridgman furnace, where the melt was cooled at a controlled rate of 0.5°C/hr and simultaneously translated through the temperature gradient at 1 mm/hr. The elemental composition of the crystals was verified using Wavelength Dispersive X-Ray Fluorescence (Rigaku Supermini200). The Laue X-ray diffraction pattern indicates that the $Sn_{0.995}In_{0.005}$ sample is not a good quality single crystal. Low temperature tests were done on this sample to verify that the allotropic transition is hindered.

For radiopurity measurements, a piece of each crystal was counted in the Tifr Low background Experimental Setup (TiLES) [4, 5], in a close geometry (∼1 cm from the face of the detector). Table I gives details of measurements. Energy spectra were acquired using a commercial 14-bit CAEN N6724 digitizer (100 MS/s) and anaylsed using LAMPS [6].

Figure 1 shows the spectra of Sn-In samples along with suitably scaled background spectrum.

TABLE I: Details of spectroscopy measurements of Sn-In samples

Sample	Dimensions h x d (mm^2)	Mass (g)	T_{count} (days)
0.5% In	18 x 12	7.3	7.5
16% In	22 x 9	5.0	4.4

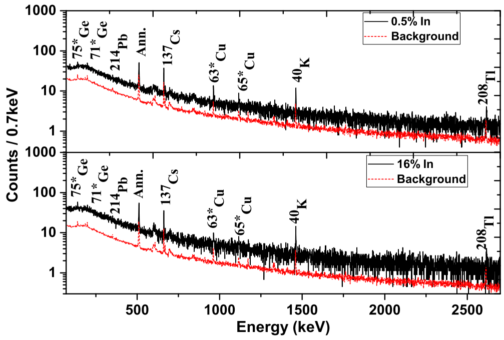

FIG. 1: Gamma-ray spectra of Sn-In samples. Scaled background spectra are showed for comparison

TABLE II: Intensities of prominent gamma-rays

Energy (keV)	Source	Bkg (cts/d)	0.5% In (cts/d)	16% In (cts/d)
139.4	^{75*}Ge^{a}	30 (3)	38 (8)	34 (8)
197.9	^{71*}Ge^{a}	31 (3)	32 (11)	40 (16)
351.9	^{214}Pb	13 (2)	11 (6)	13 (6)
511.0	Ann.^{b}	214 (6)	209 (10)	207 (13)
609.3	^{214}Bi	14 (2)	-	14 (4)
661.7	^{137}Cs	86 (3)	90 (6)	92 (12)
962.1	^{63*}Cu^{c}	23 (2)	27 (4)	40 (9)
1115.5	^{65*}Cu^{c}	12 (2)	7 (2)	16 (8)
1460.8	^{40}K	32 (2)	31 (4)	27 (9)
2614.5	^{208}Tl	16 (1)	12 (3)	13 (6)

[a] neutron induced reaction in the HPGe detector
[b] other sources are ^{208}Tl,^{40}K
[c] neutron induced reaction in the Cu shielding

Table II lists intensities of the prominent background gamma-rays. No additional lines or enhancement of background lines is observed in the spectra of Sn-In samples. The comparison of background corrected integral counts in two energy regions, namely, R1 and R2 corresponding to 100 - 2000 keV and 2000-2900 keV respectively, is shown in Table III. It is observed that $Sn_{0.84}In_{0.16}$ shows higher integral counts in both energy regions as compared to $Sn_{0.995}In_{0.005}$.

TABLE III: Comparison of the integral counts in regions R1 (100-2000 keV) and R2 (2000-2900 keV)

Sample	R1 ($g^{-1}day^{-1}$)	R2 ($g^{-1}day^{-1}$)
0.5% In	106 (8)	14 (2)
16% In	135 (16)	21 (4)

Conclusion

Gamma-ray spectroscopy using TiLES was used to study the radiopurity of tin crystals doped with indium (0.5% and 16%). No activity was found in either of the samples above the background at the measured sensitivity level of TiLES, however net integral counts in spectrum are found to increase with indium concentration. It would be important to investigate the neutron induced background in these samples.

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