Study of radioactive impurities in NTD Ge sensors for mK thermometry

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Introduction

The NTD (Neutron Transmutation Doped) Ge sensors have been widely used for mK thermometry in rare decay studies like double beta decay and dark matter searches. These sensors are preferred due to their homogeneous doping and good reproducibility. The development of NTD Ge sensors has been initiated for the first time in India by the thermal neutron irradiation of ^{nat}Ge at Dhruva reactor, BARC [1, 2]. The sensors are intended for use in TIN.TIN (The India-based TIN detector) with a Tin cryogenic bolometer to search for $0\nu\beta\beta$ decay in ^{124}Sn. We have earlier reported that the neutron irradiation of the Ge sample leads to significant levels of long-lived radioactive impurities, which can be removed by chemical etching ~ 50 μm of the NTD Ge [3]. However, since the NTD Ge sensors are required for rare event studies it is desirable to minimize the production/activity of radioactive nuclides in the sample. Therefore, different processing of Ge wafers prior to irradiation have been tested and the results are reported in this paper.

Experimental Details

The presence of surface impurities in Ge samples is potential source and the impact of these surface impurities needs to be assessed. We have studied natural Ge samples (1 mm thick) from two manufacturers with different pre-processing methods. The device grade Ge is from University Wafer and is single side polished (SSP), while the detector grade is from M/S Umicore and is not polished on either side. All these samples are expected to have trace impurities due to cutting and polishing process. Therefore SSP samples (where polishing is expected to leave more residual impurities) were chemically etched to remove 0-40 μm thickness. Chemical etching of the samples was done using H_2O_2 at 80^0C in an ultrasonic bath. All the Ge samples were cleaned with HF (40%), rinsed with deionized water, and finally blow dried with dry N_2. The samples were stacked and wrapped in a high purity Al foil. Details of various samples are given in Table I. The neutron irradiation was done for a period of $\sim$ 7 d at the Dhruva reactor, BARC. After requisite cooling period ($\sim$ 45 d), the irradiated Ge samples were counted with an efficiency calibrated HPGe detector, shielded with 5 cm thick Pb. Data was recorded using a commercial CAEN N6724 digitizer (14-bit, 100 MHz). The samples were counted in a close geometry for higher efficiency and at 10 cm from the face

TABLE I: Details of Ge samples studied

Name	Grade	ρ (Ω-cm)	Surface	Mass (mg)	Etched depth (μm)
R1	device	30	SSP	556.5	0
R2	device	30	SSP	1015.0	20
R3	device	30	SSP	1141.6	40
R4	detector	1.6×10^5	-	1429.2	0

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of the detector. The analysis is performed using LAMPS software and ROOT framework.

Data Analysis and Results

The thermal neutron fluence was monitored using ^{nat}Zr (mass 1.4 mg) sample and is calculated as 3.8 (0.4) $\times$ 10^{18} n cm^{-2} from the observed activity of ^{95}Zr [4]. It should be mentioned that this is also consistent with expected fluence during irradiation ($\sim$ 3.52 $\times$ 10^{18} n cm^{-2}). Figure 1 shows the gamma-ray spectra of irradiated Ge samples (R1, R2) counted in a close geometry for a period of 4 h.

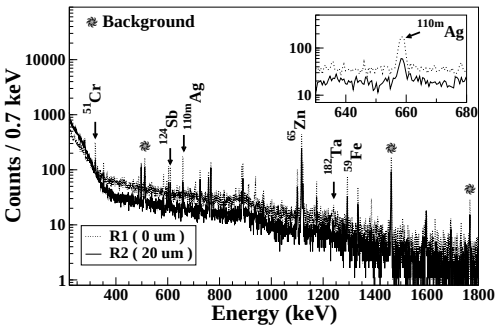

FIG. 1: Gamma-ray spectra of the irradiated Ge samples (R1, R2) counted in a close geometry. The inset shows the expanded region of ^{110m}Ag

It can be seen that etching the samples prior to irradiation reduces the level of radioactive nuclides. The comparison of the two different grades of the irradiated Ge samples is shown in Fig. 2. Each spectrum have been normalized to the mass of the R1 sample. The R4 sample showed overall higher levels of activity and also additional ones like ^{192}Ir ($T_{1/2}$ = 73.8 d). Table II gives the observed levels of the impurities in the different samples in comparison with R1 (the pristine device grade sample). That is, A_i is the ratio of counts observed in the i th sample w.r.t. the counts in the R1 sample for the corresponding gamma ray. It is evident that the etching of the Ge samples prior to irradiation resulted in reduction of the impurity levels by 40-80%. The detector grade Ge wafer (R4), which has much higher resistivity, showed higher concentrations of long-

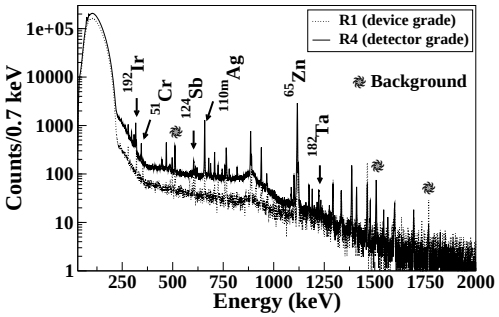

FIG. 2: Gamma-ray spectra of the irradiated Ge samples (R1, R4) counted in a close geometry.

TABLE II: Impurity levels observed in the R2, R3, R4 samples w.r.t. the R1.

Isotope	$T_{1/2}$	E_γ (keV)	A_2	A_3	A_4
^{51}Cr	27.7 d	320.1	0.33(5)	0.30(5)	0.5(3)
^{124}Sb	60.2 d	602.7	0.6(1)	0.6(1)	1.6(3)
^{110m}Ag	249.76 d	657.8	0.25(4)	0.19(3)	4.3 (6)
^{46}Sc	83.79 d	889.3	0.43(4)	0.47(4)	0.58(7)
^{59}Fe	44.5 d	1099.3	0.48(6)	0.40(5)	0.9(1)
^{65}Zn	243.66 d	1115.5	0.56(3)	0.40(2)	3.6(2)
^{60}Co	5.27 y	1173.2	0.62(2)	0.6(1)	72(12)

lived nuclides like ^{110m}Ag, ^{124}Sb, ^{65}Zn, ^{60}Co. However, on etching this sample by 20 μm, no activity above the sensitivity level of the counting setup was observed. Hence, the activity in irradiated R4 sample is due to the surface impurities and further studies are required on the detector grade samples.

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References

[1] S. Mathimalar et al., Nucl. Inst. Meth. B, **345** (2015) 33.
[2] A. Garai et al., J. of Low Temp. Phys. **184** (2016) 609.
[3] S. Mathimalar et al., Nucl. Inst. Meth. A **774** (2015) 68.
[4] G. Gupta et al., Proc. of DAE-BRNS Symp. on Nucl. Phys. **60** (2015) 914.