Defect studies of n-irradiated Ge samples

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Introduction

The R&D for prototype cryogenic tin bolometer (operating at 10 mK) for feasibility study of Neutrinoless Double Beta Decay in ^{124}Sn has recently been initiated [1]. In a cryogenic bolometer, energy deposited by incoming radiation is detected through the resultant temperature increase. Thus, it is essential to have low temperature sensors with very good resolution and sensitivity. Moreover, as this involves pulse detection, the sensor should have fast rise time.

Neutron Transmutation Doped (NTD) Ge/Si sensors are well suited for mK measurements and are widely used [2]. The NTD sensors have low specific heat and hence fast rise time, high dR/dT-which can be adjusted by doping levels and are found to show good reproducibility. The NTD Ge sensors are produced by irradiating with the thermal neutrons in a reactor, which yields an uniform doping. However, during the irradiation the Ge crystal is also exposed to fast neutrons, which can create defects and can affect the performance of sensors. Thus, defects in NTD Ge sensors due to neutron irradiation need to be investigated. This paper reports the defect studies of neutron irradiated Ge samples using Positron Lifetime Annihilation Spectroscopy (PALS) and channeling. Both these methods are expected to give complementary information.

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Experimental details and analysis

Semiconductor grade Ge crystals (<111> cleavage plane, 0.4 mm thick) of size 10mm x 10mm are irradiated with a reactor neutron exposure corresponding to thermal dose of 1.65 x 10^{19} n/cm^2(NTD B) and 0.97 x 10^{19} n/cm^2(NTD C) at Dhruva reactor, BARC. After an initial cool-down period of 45 days, samples were counted in low background counting facility at TIFR [3]. In addition to the gamma rays of interest, ^{109}Ag and ^{181}Ta impurities are also present at ppb level. Scanning Electron Microscope (SEM) pictures indicated a few micron size patches on irradiated samples. The VI characteristics of one of the irradiated samples was measured in the range 30-300 K. The defect studies are carried out in 3 sets of samples, namely, virgin sample (unirradiated), irradiated sample (without annealing)and irradiated sample after annealing at 600°C for 2 hours in Ar atmosphere.

In a defect free crystal, the β^+ interacts with a valance electron and annihilation leads to two 511keV γ-rays. In presence of defects the β^+ can remain trapped in the defect due to the strong repulsive force from core ions and the observed β^+ lifetime will be longer. For PALS measurement the ^{22}Na (~8μCi) was sandwiched between two identical (virgin/irradiated) Ge samples and were mounted between two plastic scintillators kept at 180° w.r.t. each other. The β^+ lifetime is obtained from TAC spectrum with 1.27MeV γ-ray as a start signal and 511keV γ-ray as a stop signal. The measured β^+ lifetimes are given in TABLE I. The τ~228ps measured for virgin sample is consistent with that of a bulk Ge crystal (228ps). The τ~293.6ps for irradiated samples, indicates that defects are of 'monovacancy' type. As β^+ undergo saturation trapping, exact concentration can not be inferred and is estimated to be 0.1% in irradiated samples. The τ~225.6 ps observed for the annealed sample is very similar to that of the virgin crystal.

TABLE I: $T_{\beta+}$ using PALS in NTD-B

Samples	$T_{\beta+}$ (ps)	*Ref* (ps) [4]
Virgin Ge	227.8 ± 0.3	228 (bulk)
Irr. Ge	293.6 ± 0.4	292 (Monovacant)
Annealed Ge	225.6 ± 0.3	-

The crystal channeling is sensitive tool for probing interstitial and strain related defects [5]. The channeling experiment with 2MeV alpha particles has been carried out using PARAS facility at IUAC [6], using Rutherford back scattering (RBS) at a scattering angle of 170°. The beam current is kept lower than 10nA to minimize the damage. Figure 1 shows an axial scan of virgin and irradiated Ge samples. No significant change in the channeling dip, either in the minimum yield or the width of the dip, is visible within measurement errors.

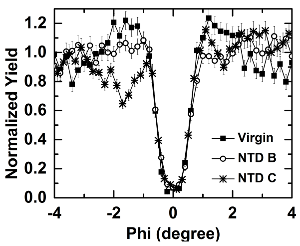

FIG. 1: Axial scan of Ge samples

Figure 2 shows the RBS spectra along <111> axis for virgin and irradiated sample together with that for random orientation. The defect density N_D is estimated using the RBS yield along the axis, following the procedure described in Ref. [7] (see TABLE II).

$$N_D = N \left[\frac{\chi_{min}^{irr} - \chi_{min}^{o}}{1 - \chi_{min}^{o}} \right] \quad (1)$$

Where N is the number of Ge atoms, χ_{min}^{irr} is the χ minima of the irradiated sample and χ_{min}^{o} is that of Virgin sample.

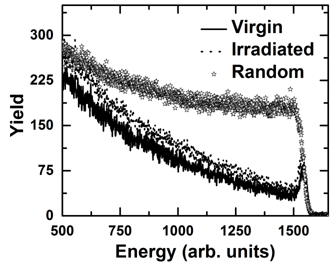

FIG. 2: RBS spectra of Virgin & Irradiated Ge

TABLE II: Estimated N_D from channeling

Samples	*n flux/cm*^{2}	*Defect density/cm*^{3}
NTD B	1.6 x 10^{19}	(7.3 ± 1.2)x 10^{20}
NTD C	0.97 x 10^{19}	(3.2 ± 0.4) x 10^{20}
Ratio	1.65	2.3 ± 0.4

Conclusion

The PALS results show that NTD Ge have 'monovacancy' defects, which are sufficiently cured by annealing at 600°C for 2 hours in Ar atmosphere. The defect density estimated from channeling is proportional to the neutron dose but no significant damage was observed. Therefore, the NTD Ge samples after annealing are good for sensor fabrication.

We thank S. Mishra, Dr. G. Ravikumar and Dr. A.K. Rajrajan for helping.

References

[1] V. Singh *et. al.,* AIP Conf. Proc. **1405**, 334 (2011)
[2] P. Gorla, J. Phys. Conf. Ser. **375**, 042013 (2012)
[3] N. Dokania *et. al.,* DAE symp. on Nucl. Phys. **56** 1136 (2011)
[4] R.K. Rehberg, H.S. Leipner, Positron Annihilation in Semiconductors - Defect Studies (Springer Pub.) p186, 1999
[5] D. S. Gemmell, Rev. Mod. Phys., **46**, 1 (1974)
[6] http://www.iuac.res.in/accel/paras
[7] M. Satoh and K. Kuriyama, J. Appl. Phys. **67**, 3890 (1990)