Estimation of carrier concentration of a NTD Ge from the resistivity measurement at 4K

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Introduction

A Sn based cryogenic bolometer is being developed to study neutrinoless double beta decay (NDBD) in ^{124}Sn. The key element of the detector is a NTD Ge temperature sensor. NTD's are preferred due to its dynamic range and easy read out. NTD Ge sensors have been developed at TIFR, Mumbai by irradiating a bare Ge wafer in Dhruva reactor at BARC, Mumbai [1]. These sensors are intended to be used as a temperature sensor operating at around 10 mK. The performance of NTD Ge sensor strongly depends on the neutron fluence. It should be pointed out that the neutron fluence cannot be precisely controlled during the irradiation. Hence, independent measurements on the neutron fluence is important. The performance of an irradiated Ge wafer is evaluated by fabricating sensors following an elaborate process [2] and testing in a dilution refrigerator. It may be worthwhile to measure the resistivity of the wafer in a relatively simpler setup which can predict the performance of the sensor at mK temperature saving a lot of time and effort. Navick et al., have shown [3] that the resistivity ratio at 77K to 4K is particularly useful for this purpose. Moreover, this measurement can provide an independent and more precise measurement of the neutron fluence in addition to that obtained from Zr and Sb activity [4].

Experimental details

The irradiated Ge wafer is etched with $HF+HNO_3$ solution. The etched wafer is annealed at approximately 600^0 C to remove the crystal defects that may have incurred in irradiation process. A small piece (usually $3x3mm^2$) is cut from the wafer for testing purpose. The sample is then mounted on an insert-able probe using GE Varnish. Two 25 µm Al wires are wedge bonded to copper pads for making electrical contacts. A previously calibrated cernox sensor (calibrated against PT1000) was used as thermistor for monitoring the temperature of the setup.

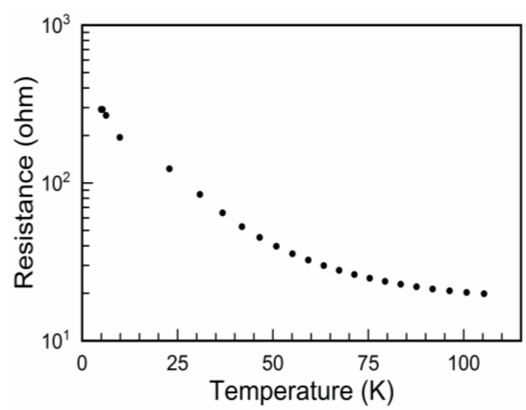

Fig 1: R vs T for a typical usable sensor (in fig DM1 sample) in range of 4 to 100 K. Error bars are within the symbol size.

The probe was evacuated and filled with about 0.5 mbar of dry ^{4}He as an exchange gas. The entire setup is lowered inside a liquid ^{4}He cryostat for achieving the variable range hopping temperature (<10K). The cooling rate was observed to be slow enough to consider the resistance to be in thermal equilibrium over the measurement time interval. Resistance values of the sample and the thermistor are measured with a Lakeshore 370 AC resistance bridge. A LabView based program for recording the resistance was developed.

Results

Typical behavior of the resistance vs temperature (T ~ 4K-100K) is shown in Fig 1. This temperature region consists of two regions, a) T<10K where the conductivity switches to variable range hopping and other b) T~10-100K where the carriers starts to freeze out. The resistance values in two regions, R_a and R_b, their ratio depends on carrier concentration and hence can be used to estimate incident neutron fluence.

Table 1: Ratio $R_0(=R_{5K}/R_{77K})$ over the entire fluence range.

Sample name	Resistance(Ohms)		Fluence $x10^{18}$ $n*cm^{-2}$	Ratio R_0
	@5K	@77K		
Q1	141.6	106(6)	20.4	1.34(8)
Q2	222.3	166(8)	20.4	1.34(6)
V	60	30(5)	9.5	2.0(3)
DM1	293	23.8(1)	4.6	12.3(6)
M	488.7	31(1)	3.8	16.1(7)
K2	544.7	35.4(9)	2.4	15.4(4)
E	5730	82(2)	1.8	70(2)
I	12065.7	91(4)	1.7	130(7)
AH_1	15.8	9.9(1)	-	1.60(2)
AI_1	5838	34.7(5)	-	168(2)

At T<10K, the resistance varies with temperature as $R=R'\exp(\sqrt{T_0}/\sqrt{T})$, where T_0 depends on fluence and this scalability is apparent from graph in Fig 2. In the current setup, the lowest temperature achieved is about 5K. Hence ratio, $R_0 = R_{5k}/R_{77K}$ is measured and shown in graph. The graph is empirically fitted with an exponential function. To extract the neutron fluence of an unknown sample, R_0 can be measured and fluence can be obtained from the fit function. The fluence for AH_1 and AI_1 sample was measured using Zr activity and the value obtained were $1.0x10^{19}$ and $0.73x10^{18}$ n/cm^2 respectively. This data point was found to sit well in the fitted data of other known fluence.

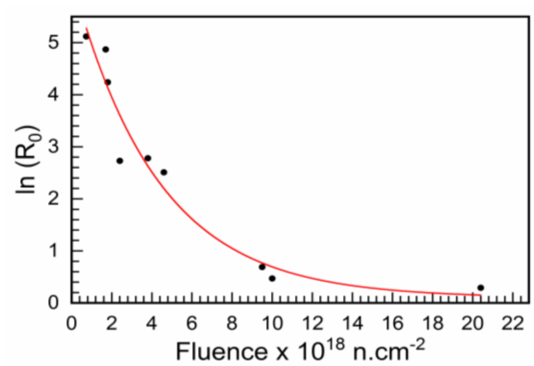

Fig 2: Logarithmic plot of R_0 vs neutron fluence together with the empirical fit. Error bars are within symbol size.

Conclusion

Resistive measurement is done to estimate the carrier concentration of NTD Ge to be used for mK experiments. From the fitted graph, this predictive method seems to determine if the NTD is in optimal dose of fluence or not. More statistics are required for better fitting parameters and estimation.

Acknowledgement

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