Development of NTD Ge Sensors for Superconducting Bolometer

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Introduction

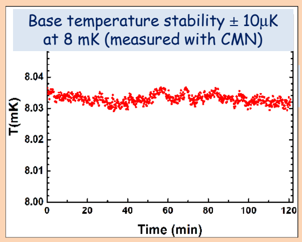
- Prototype development of superconducting Tin cryogenic bolometer **(TIN.TIN : The India-based TIN Detector)** to search for 0νββ in ^{124}Sn at the upcoming India-based Neutrino Observatory has been initiated [1].
- Development of Neutron Transmutation Doped Ge sensors for low temperature (mK) thermometry [2] : indigenous effort to fabricate NTD Ge sensors in India
- **Characterization of sensors at T < 300 mK**
  - Optimization of electrical contacts
  - Verification of temperature dependence of R (Mott's law)

The India-based TIN Detector (TIN.TIN)

- Sn becomes superconducting below T_C ~ 3.7 K and can be made into a bolometric detector (T<100 mK) with excellent energy resolution.
- ^{124}Sn ⟶ ^{124}Te*, $Q_{\beta\beta}$ = 2292.64 ± 0.39 keV, Natural Isotopic Abundance 5.79 %
- A cryogen-free dilution refrigerator (CFDR-1200, Leiden make) installed at TIFR [3]. It has a large sample space and an additional option of a top loading probe (sample space ~ 40 mm dia, 80 mm long) to facilitate easy sample changes at cold condition.

Top loading probe

Base temperature stability ± 10μK at 8 mK (measured with CMN)



- Minimum temperature without probe ~ 8 mK, with probe ~ 12 mK
- Cooling power 1.4 mW @120 mK with about 50 lit. of ^{3}He
- Provision to mount electronics at 40 K stage

Fabrication of NTD Ge

- Device grade <100> Ge samples (1 mm thick) are irradiated with thermal neutron fluence of ~ (1.8 – 4.6) x 10^{18} n/cm² at Dhruva Reactor, BARC, Mumbai, India [4].
  - Typical sample size 10 mm x 30 mm, wrapped in aluminum/quartz
  - A few micron surface layer etched away to remove radioactive impurities
- Irradiated samples vacuum annealed at 600 ^{0}C for ~ 2 h to cure fast neutron induced defects.
- Carrier concentration estimated using Hall effect measurements at 77 K [5].

Table 1: Thermal neutron fluence and carrier concentration of NTD Ge samples

NTD Ge Sample	Thermal neutron fluence (n/cm²)	Carrier Conc. (/cm³)	
		n-flux	Hall effect
D	4.57 x 10^{18}	1.11 x 10^{17}	1.11 x 10^{17}
G	3.57 x 10^{18}	8.68 x 10^{16}	-
F	3.52 x 10^{18}	8.55 x 10^{16}	-
E	2.11 x 10^{18}	5.13 x 10^{16}	4.45 x 10^{16}
H	1.8 x 10^{18}	4.37 x 10^{16}	4.17 x 10^{16}

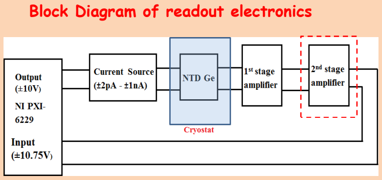
Sensor Test Setup and Readout electronics

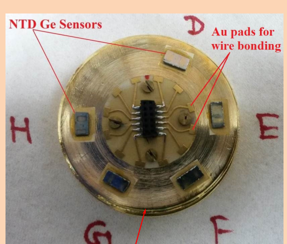
Electrical contacts for readout:

- ~ 100 nm Au-Ge deposition by sputtering
- Rapid Thermally Annealed at 400 ^{0}C for 2 min.
- Electrical connections made by Al/Au wire bonding.

NTD mounting arrangement

Block Diagram of readout electronics





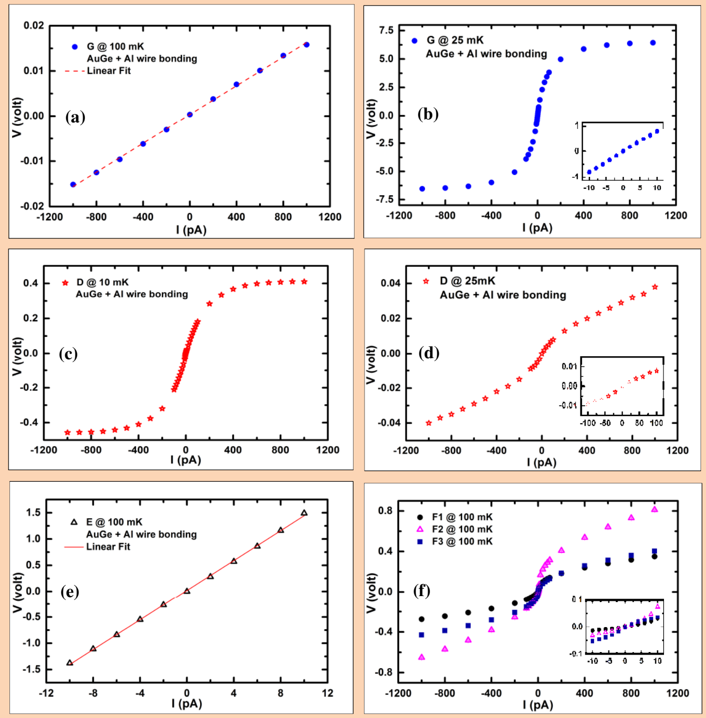
Au plated Cu thermal sink.

- Low noise pA Current source : CSE09NV, range ± 1 nA, Resolution 2 pA (RDM apps make).
- Low noise Voltage amplifier: INA 116, Gain 1 – 1000.
- DAQ developed with NI PXI 6229 using Labview signal express.

Resistance Measurements at T ≤ 100 mK

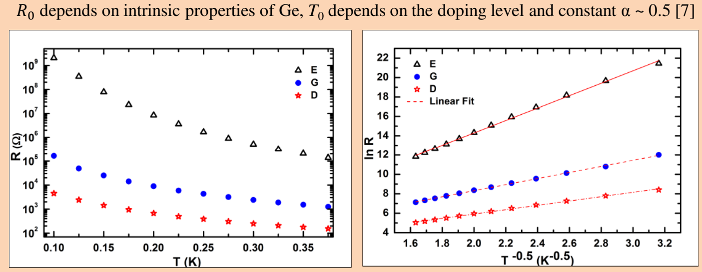
V-I measurements performed to check the Ohmic nature of the metal semiconductor contact

- Most of the samples showed good Ohmic behaviour at 100 mK, but at lower T (10 - 25 mK) Schottky barrier like nonlinearity is seen (panels *a – e*, amplifier gain ~100)
- Observed saturation could also be due to self heating at high current. Therefore ***R*** is extracted from slope near the origin.
- One of the samples did not show good Ohmic contact even at 100 mK. Different metal wires Al, Au etc. gave similar results (shown in panel *f*).
  F1 : 100 nm AuGe pad and Al wire, F2 : 100 nm AuGe + 100 nm Au pad and Al wire,
  F3 : 100 nm AuGe + 100 nm Au pad and Au wire.



For NTD Ge sensor temperature dependence of R is given by [6] : $R = R_0 \exp[\frac{T_0}{T}]^{\alpha}$

R_0 depends on intrinsic properties of Ge, T_0 depends on the doping level and constant α ~ 0.5 [7]



Sample	Thermal neutron fluence (n/cm²)	T_0 (K)	R_0 (Ω)
D	4.57 x 10^{18}	4.9 ± 0.2	4.3 ± 0.3
G	3.57 x 10^{18}	9.8 ± 0.2	7.9 ± 0.5
E	2.11 x 10^{18}	41 ± 1	4.5 ± 0.9

ln R varies linearly with $T^{-0.5}$

- Even though the sensors are of very similar geometry, fitted values of R_0 are different.
- Similar behavior reported in Ref. [8]. It is suggested that residual stress, unannealed radiation damage and dislocations may cause this variation at very low temperatures.

Conclusion & Future Outlook

- NTD Ge sensors have been fabricated, for the first time in India, with high dR/dT ~ 100 MΩ/mK.
- Measurements in 100 – 350 mK range indicate that for fabricated sensors ln R α $T^{0.5}$
- Improvements in design of electrical contacts are in progress.
- Optimization of neutron dose required for large scale production.

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