SuperCDMS SNOLAB: Road to 100 mm Germanium Detectors

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interleaved Z-sensitive Ionisation & Phonon detector (iZIP)
3”$\phi \times 1”$ thick, 600 g Ge crystals
Simultaneous measurement of phonon & charge signals
Interleaved electrodes so surface events show up on one detector side only
iZIP technology appears to meet requirements for larger target masses

Scaling difficult: $\sim 340 \, 3'' \phi \times 1''$ crystals for 200 kg mass

A number of factors make this expensive:

- Increased manpower: fabrication and testing are labour intensive
- Increased heat load: additional wiring to room temperature
- Increased cold hardware and warm electronics

Increasing the size of individual detectors can help alleviate these issues
The Road to 100 mm Germanium Detectors

- Up to 100 mm diameter detector-grade Ge crystals can be grown
- Three crystals of thickness 33.3 mm and mass 1.37 kg have been/are being tested:
  1. Ionisation test device
  2. Spiral electrode device
  3. First 100 mm iZIP design
- Tests performed with existing CDMS-II 3” cold hardware with minor modifications:
  - CDMS-II tower, side coaxes, cold electronics cards and striplines
  - New extender plug to bridge gap between tower and side coax
  - New detector housing to encase larger diameter crystal
- Tests utilise new warm electronics designed for SuperCDMS SNOLAB
The 100 mm Ionisation Test Device

- Sections of two inner electrodes extend through gaps to bring them closer to the detector edge for readout.
- Uniform grid at ground present on opposite face.

- Ionisation electrodes patterned as 4 concentric rings.
- Crystal volume of 64.3 cm³ lies under each electrode for comparable responses.
- Electrodes separated by 400 μm wide trenches.
- Each electrode consists of a grid of 2 μm thick wires at pitch of 40 μm.
Ionisation Measurements

60 keV $\gamma$-rays from four $^{241}$Am sources used for ionisation measurements

Each source collimated (activity $\approx$ 20 Bq)

Each source placed above centre of electrode as shown by red dots
Mean free path of 60 keV $\gamma$-rays in Ge is $\sim 1$ mm

Vary bias and determine change in position of 60 keV peaks

Outer channel Q4 used as veto

Uncalibrated charge spectra
-4.0 V bias

100 mm $\phi \times 33.3$ mm thick crystal

G102 Charge Collection Efficiency
Charge Collection Efficiency

- Mean free path of 60 keV $\gamma$-rays in Ge is $\sim 1$ mm
- Vary bias and determine change in position of 60 keV peaks
- Outer channel Q4 used as veto

30 mm $\phi \times 10$ mm thick crystal

100 mm $\phi \times 33.3$ mm thick crystal

- Results consistent with scaling past measurements on 1 cm thick crystals:
  - Bias voltage of 1.7 V required for complete charge collection
  - These crystals have necessary charge collection efficiency to be operated as dark matter detectors
Use 356 keV line from external $^{133}$Ba source to measure charge collection efficiency in bulk

Three inner electrodes exhibit similar response

Charge collection efficiencies measured with $^{241}$Am & $^{133}$Ba sources are consistent
Ionisation Signal Stability

- Ionisation signal stability increases with bias
- Similar behaviour seen collecting electrons as that when collecting holes

![Graphs showing Q2(cQ2) vs Time for -4.0 V and -6.0 V bias]

- Short bursts of LED flashes over a period of < 6 s successfully remove charge traps and reset detector to its original state

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The Spiral Electrode Device

- Inner disk covers ~ 66% of surface area
- Centres of grounded and charge ribbons lie 1.5 mm apart
- Top side is mirror of bottom face

- Two electrodes on each crystal face: inner disk and outer ring
- Grounded ribbon of width 250 \( \mu m \) interleaved with charge ribbons of width 40 \( \mu m \)
Identification of Surface Events

- One $^{241}$Am source installed facing inner charge channel on Side 2
- Mean free path of 60 keV $\gamma$-rays in Ge is $\sim 1$ mm
- Grounded and charge ribbon centres lie 1.5 mm apart
- Electrons/holes from 60 keV events mostly show up on Side 2

![Charge Spectrum: Side 2 bias = -4.0 V](image)

![Location of Am-241 Qinner 60 keV events](image)

Figure on right:
- $z$-partitioning = \(\frac{(\text{Side}1 - \text{Side}2)}{(\text{Side}1 + \text{Side}2)}\), radial partitioning = 0 is central cylinder axis,
- timing cut defined as (Time of event) < 150 s from start of data acquisition
Charge Collection Efficiency

- 356 keV line from external $^{133}$Ba source used to measure charge collection efficiency in bulk
- Curves normalised to unity at $-12$ V bias
- Charge collection efficiencies for both sides are reasonably uniform
The First 100 mm iZIP

- Centres of phonon and charge ribbons lie 1.5 mm apart
- Phonon channels rotated by 45 degrees about central axis on bottom face
- Two electrodes on each crystal face: inner disk and outer ring
- 12 phonon channels, six on each side
- Phonon ribbons of width 260 µm interleaves with charge ribbons of width 50 µm
First Phonon Pulses

- Readout through 3 Device Interface Boards (DIBs), to which CDMS-II side coaxes are attached

- Phonon pulse decay time $\approx 0.8$ ms, in line with what we expect

- Transition Edge Sensors’ (TES) critical temperatures lie between 76 mK & 86 mK

- No significant difference between critical temperatures on both sides
Cryostat surrounded by new lead-polyethylene shield which should reduce background flux by a factor of $\sim 5$ at surface testing facility

- Detector exposed to $^{133}$Ba source for half-an-hour
- Peaks at 302 keV & 356 keV very clear
- Peak at 384 keV visible
- Ionisation signal stable for at least 30 minutes at -4.0 V bias
100 mm diameter Ge crystals have necessary charge collection efficiency to be operated as dark matter detectors.

iZIP principles, such as surface event rejection, can be applied to 100 mm diameter crystals.

The first 100 mm iZIP looks like a good detector and is currently undergoing detector characterisation tests.

Several 100 mm iZIP detectors in the pipeline.