SuperCDMS Crystal Defect Formation Study Data Release

SuperCDMS Collaboration

March 10, 2019

1 Introduction

This document accompanies the public release of the SuperCDMS Soudan ^{206}Pb recoil energy data and provides explanatory material related to the released files themselves. Instructions are given regarding the reproduction of published results. The energy loss and Ge displacement threshold energy results from these data are found in Ref [1]. Questions about the data or the results should be directed to `supercdms_publications@lists.astro.caltech.edu`.

2 Description of Data

The following files are included in the associated:

- `Events_T3Z1.dat`, `Events_T3Z3.dat`: These files contain the recoil energies for ^{206}Pb events in the SuperCDMS Soudan detector referred to as T3Z1 and T3Z3, respectively. Each file contains a single column of energies in keV units. The calculation of the event recoil energy is described in Refs. [2, 3]. The selection of these events is outlined in Ref [1]. There are 14,086 and 8,661 events for T3Z1 and T3Z3, respectively, with energies E in the range of $80 \leq E \leq 110$. Histograms of these events are illustrated in Figure 1.

3 Calculating Energy Loss

To determine the percent of energy lost to defect formation, as described in Ref [1], a full Monte-Carlo simulation must be performed. Specically, one must simulate the full decay chain of implanted ^{210}Pb within a Si volume. The Si volume should represent the Si source wafer described in Refs [1, 4].

The Si volume should exhibit a near-uniform implantation profile of ^{210}Pb to a depth of approximately 58 nm[4, 5]. The exterior faces of the Si volume should be simulated with (1.6 ± 0.1) nm of SiO_2. The Ge detector should also have an

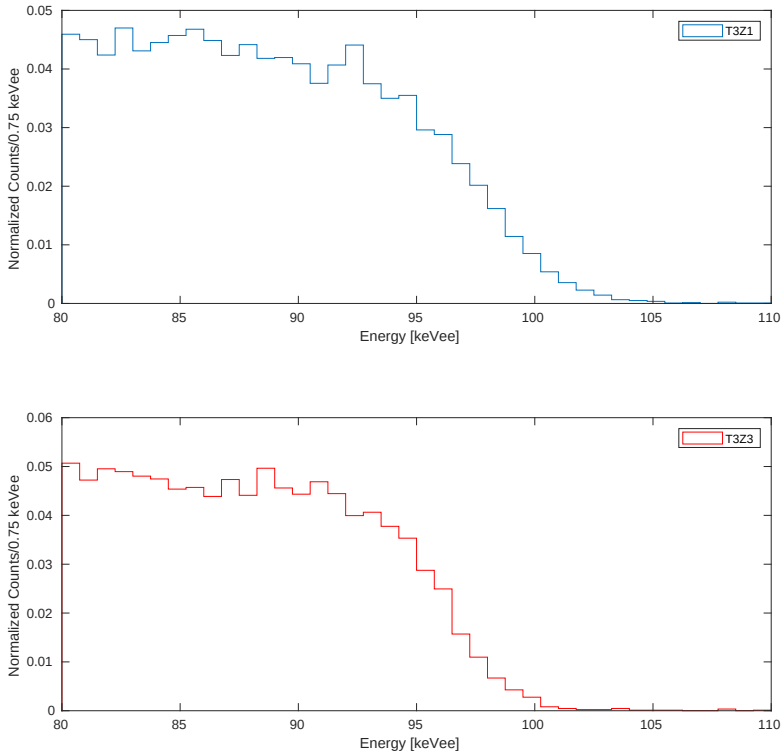

Figure 1: The recoil energies from T3Z1 (Top) and T3Z3 (Bottom) from the SuperCDMS Soudan experiment. This figure was generated from the `Events_T3Z1.dat` and `Events_T3Z3.dat` files.

exterior layer of (0.98 ± 0.02) nm of GeO_2. Further details of the experimental apparatus and the ^{210}Pb source plates are available in Ref [4].

From the Monte-Carlo simulation, the events of interest are those in which heavy ions leave the Si volume and recoil within the detector. It is important to not discriminate against ion species. Although rare, sputtered Si and O may deposit energy in the Ge detector and these events should not be ignored.

A list of recoil energies for all impinging particles should be created, similar to the format of the `Events_T3Z1.dat` file. The sets of simulated and measured energies are compared as sets A and B in Ref [1]. By minimizing the χ^2 statistic, the best-fit energy loss is determined.

4 Determining the Ge Displacement Threshold Energy

TRIM[6], a part of SRIM, can be employed to determine the Ge displacement threshold energy. TRIM is a software program that runs on the Windows operating system and can be downloaded for free at http://srim.org/.

TRIM calculates the range and energy loss mechanisms of ions in matter. To reproduce the Ge displacement threshold value results, `TRIM.dat` file will need to be created. This file specifies unique impinging particles in a TRIM simulation. Each particle can be a different species with a unique mass, kinetic energy, and incident angle. An example `TRIM.dat` file is included with the SRIM software package. Details of the usage of this file are given in the `HELP - TRIM Input.pdf` file.

The Monte-Carlo simulation described in the preceding section should be used to populate the `TRIM.dat` file: each impinging particle would have its own line with Z, mass, incident kinetic energy, and incident angle. The kinetic energy must be the energy of the ion as it leaves the Si volume.

To use the `TRIM.dat` file, follow these steps:

- Open SRIM via "SRIM.exe" and click "TRIM Calculation."
- Under "DAMAGE," choose "Ions with specific energy/angle/depth (full cascades) using TRIM.dat."
- GeO_2 layer: Under "Input Elements to Layer," add Ge and O. Note the displacement threshold value for Ge. For O, change "Atom Stoich" to 2. Under "Target Layers," change the width of this layer to 9.83 Å. Change the density to $4.228\,\mathrm{g/cm^3}$.
- Pure Ge layer: Under "Target Layers," add a new layer. To the new layer, add Ge. Again, note the Ge displacement threshold value. Change the width of this layer to $10,000$ Å.
- In the bottom left-hand corner of the TRIM window, change the "Random Number Seed" value every time TRIM is run.

- Click "Save Input & Run TRIM" when ready.

Using the same TRIM.dat file, the simulation should be performed with varying Ge displacement threshold energies. TRIM will calculate the percentage of incident energy that goes into the formation of defects. TRIM also discriminates between defects created by the original incident ion (*i.e.* Pb-on-Ge) and defects created by knocked-on atoms (*i.e.* Ge-on-Ge). The total energy lost to defects the sum of both of these. In the GUI, all energy losses are shown in the "% ENERGY LOSS" window. The sum of every cell is 100%, and the cells relevant to defect formation are those in the "Vacancies" row.

By performing this simulation over various Ge displacement threshold values, a trend can be developed which relates this value to the percent energy loss to defect formation. The measured energy loss can be used to therefore determine the Ge displacement threshold value, as calculated by TRIM.

To determine the uncertainty from varying the GeO_2 layer, the same procedure is applied as above, but with ± 0.02 nm for the GeO_2 thickness.

References

[1] R. Agnese et al. Energy loss due to defect formation from 206pb recoils in supercdms germanium detectors. *Applied Physics Letters*, 113(9):092101, 2018.

[2] R. Agnese et al. Results from the super cryogenic dark matter search experiment at soudan. *Phys. Rev. Lett.*, 120:061802, Feb 2018.

[3] R. Agnese et al. Low-mass dark matter search with cdmslite. *Phys. Rev. D*, 97:022002, Jan 2018.

[4] R. Agnese et al. Demonstration of surface electron rejection with interleaved germanium detectors for dark matter searches. *Applied Physics Letters*, 103(16):164105, 2013.

[5] P. Redl. Accurate Simulations of Pb Recoils in SuperCDMS. *Journal of Low Temperature Physics*, 176:937–942, September 2014.

[6] J. F. Ziegler, M. D. Ziegler, and J. P. Biersack. SRIM - The stopping and range of ions in matter (2010). *Nuclear Instruments and Methods in Physics Research B*, 268:1818–1823, June 2010.