Dark Matter Search

Ramiro Garcia[1,2], Noah Kurinsky[1] and Mike Kesley[1]
Stanford Linear Accelerator Center[1] /STAR Program[2]

Introduction

Objective: The goal of the research was to add a physical model for the mean free path of the electron in the Lattices that match the Edelweiss data for the mean free path in Germanium.

- The SuperCDMS SNOLAB is the first low-mass dark matter detector in the cryogenics system at SLAC. It is designed to be sensitive to detect dark matter down to 300 Mev in mass and resolve individual electrons-hole pairs from low energy scattering events in high purity Ge and Si crystals.
- The purpose is to simulate electrostatic fields within the detector medium, and run detailed particle physics simulations to attempt to match simulation to observed detector response for the first time with detectors of this size using the GEANT4 simulation package, and SuperCDMS solid-state simulations.

Figure 1. *The SuperCDMS SNOLAB low mass dark matter detector in cryogenics system at SLAC*

Results

Physical model for the Mean Free path simulation

- The physics based model exactly reproduces the measured Edelweiss data as interpolated by the function discussed in the methods section. The Physical model product the same scattering rate and charge drift speed. Which, was big discovering since the Edelweiss used a best fit line that had no underling physics
- In addition, we found the parameters that are needed to implement our physical model to different types of crystals.

Scattering Rate Simulation

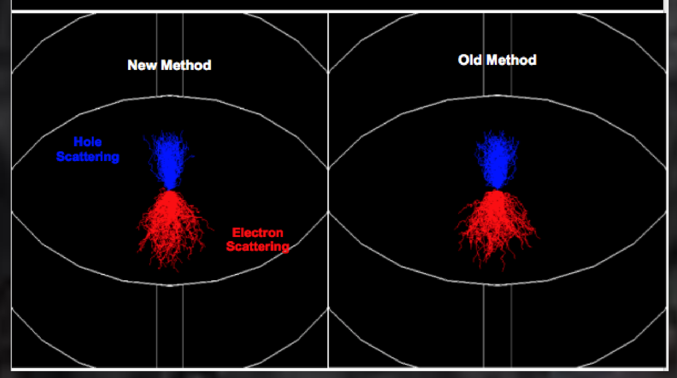

Figure 6. *The Scattering Rate Simulation of holes and electron scattering. The Graphs are Comparing the Edelweiss model vs physical model implemented at SLAC*

Charge Drift Speeds in Germanium

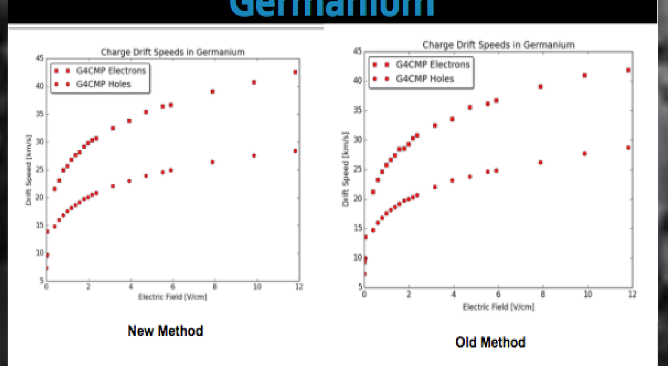

Figure 7. *The Charge Drift Speed of electron in Germanium. The graphs are comparing the Edelweiss method vs physical model implemented at SLAC*

Parameters

E_T = threshold energy (measured in eV)

n_I = number density of impurities

D_{ac} = acoustic deformation potential

D_{op} = optical deformation potential

ω_{op} = optical phonon frequency

ρ = crystal density

m_D = 'density of state' effective mass

ϵ_r = relative permittivity (to be multiplied by the permittivity of free space)

α = nonparabolicity

Figure 8. *The Parameters found using the Physical model. All parameters are in the three equation that were implemented in the computer program code.*

Methods

- Learned how a semiconductor works. Also, we used silicon and geranium in the SuperCDMS
- Learned particle physics to understand the scattering rate of atoms and holes in semiconductors depending on their electric voltage
- Collaborated in a massive programming code where I had to use github in order to implement changes in the code
- Used putty to log on to the SLAC server to pull, change, and push new code onto the server
- Changed the equation of mean free path to be dependent of electron energy instead of electric voltage. To do this I added the neutral impurity, optical, and acoustic scattering rate equations into the code; divided velocity of the electron by the sum of the three scattering rate equations.
- Figured out what were the parameters of geranium as well as their units in the lattice
- Finally, calibrated my program to run with the simulation code for detecting dark matter

Acoustic Phonon Scattering

$$\Gamma_{ac}(E) = \frac{\sqrt{2}}{\pi}\frac{k_b T m_D^{3/2} D_{ac}^2}{\hbar^4 \rho u^2}\sqrt{E(1+\alpha E)}(1+2\alpha E)$$

Figure 2. *The Acoustic Phonon Scattering equation that was coded in the GEANT4 Simulation and the actual code of the equation.*

Neutral Impurities Equation

$$\Gamma = \frac{4\sqrt{2}\pi n_I \hbar^2}{m^{3/2}}\frac{E^{1/2}}{E+E_T} \qquad E_T = 0.75\frac{m^*}{m}\frac{\epsilon_0}{\epsilon}$$

```
//Neutral Impurities
G4double epsilon_r = 16.2;
G4double epsilon = epsilon_r * epsilon0;
G4double e_r =  epsilon0/epsilon;
G4double E_T = (M_D /mass_electron) * e_r;
G4double n_I = 1e11/cm3; // The number density of impurities per cubic cm

G4double nrate = (4*sqrt(2)* n_I * hbar_sq * sqrt(energy)) /
  ( M_D3half * (energy + E_T));

if (verboseLevel>1)
  G4cout << " Neutral Impurities " << nrate << G4endl;
```

Figure 3. *The Neutral Impurites equation that was coded in the GEANT4 Simulation and the actual code of the equation*

Optical Phonon Scattering

$$\Gamma_{op}(E) = \frac{k_b T m_D^{3/2} D_{op}^2}{\sqrt{2}\pi\hbar^2\rho\hbar\omega_{op}}\sqrt{(E-\hbar\omega_{op})(1+\alpha(E-\hbar\omega_{op}))}(1+2\alpha(E-\hbar\omega_{op}))$$

Figure 4. *The Optical Phonon Scattering equation that was coded in the GEANT4 Simulation and the actual code of the equation*

Prediction of the Mean Free Path

$$MFP = \frac{v}{\Gamma + \Gamma_{ac} + \Gamma_{op}}$$

```
G4double mfp = velocity / (nrate + orateTotal + arate);

if (verboseLevel>1) G4cout << "IV MFP = " << mfp/m << " m" << G4endl;

return mfp;
```

Figure 5. *The mean free path equation*

Conclusions

- I constructed a program that implemented that physical method by calculated the mean free path using the electrons energy. That differed from Edelwiess that use the electron field to calculate the mean free path.
- The Physical method produce the same graphs as the Edelwiess method and it provides the underling physics of the electron inside the Germanium crystal.
- In addition, if there was more time I would have ran a simulation for Silicon. Also, move the parameters from the mean free path and put them in the lattices. This would allow the program to run efficient and allow the user to run different simulation with Germanium and Silicon

Bibliography

1) *Jacoboni, Carlo, and Lino Reggiani. "The Monte Carlo Method for the Solution of Charge Transport in Semiconductors with Applications to Covalent Materials." Reviews of Modern Physics, vol. 55, no. 3, Jan 1983, pp. 645–705., doi:10.1103/revmodphys.55.645.*

2) *Noah Kurinsky. "Electron Mobility and Intervalley Scattering in Si and Ge" 29 Aug 2017*

Acknowledgments

- This material is based upon work supported by the National Science Foundation through the Robert Noyce Teacher Scholarship Program under Grant #1340110. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The research was also made possible by the California State University STEM Teacher and Researcher Program, in partnership with Chevron (www.chevron.com), the National Marine Sanctuary Foundation (www.marinesanctuary.org), SLAC, and . Special thanks to Noah Kurinsky, Mike Kelsey, and Richard Partridge for their guidance and mentorship. Also, Enrique Cuellar and SLAC for giving me the opportunity to do research. Thank you to, Analise Elliot Heid and Lawrence Horvath for all the support they provide in my research.