A Quest for WIMPs

Cryogenic Dark Matter Search at Texas A&M University

Paulette Epstein[1,2], Rupak Mahaptra[1]

Texas A&M University Cyclotron Institute, University of Wisconsin-Stevens Point

Cyclotron Institute
Texas A&M University

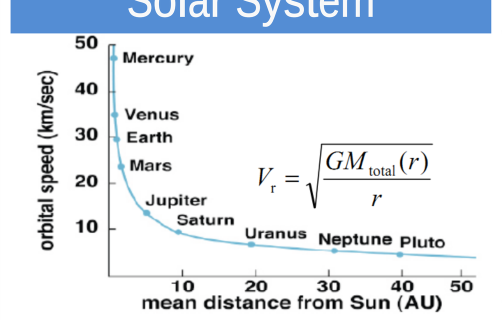
National Science Foundation
WHERE DISCOVERIES BEGIN

Abstract

Dark matter makes up about 23% of the universe but has not been directly detected. The Cryogenic Dark Matter Search (CDMS) is attempting to use low temperature germanium detectors run underground to measure signals from one possible dark matter candidate, Weakly Interacting Massive Particles (WIMPs) while eliminating background events. There have been a few recent hints of possible direct detection but none are conclusive. Because the probability of dark matter interaction scales with detector mass, CDMS plans to build and operate more and bigger detectors. Texas A&M University is working on improving the current production rate, quality, and reproducibility of fabricated detectors. An automated sputtering system is used to deposit amorphous silicon, and high quality tungsten and aluminum thin-films on 3 inch by 1 inch germanium substrates to demonstrate repeatable depositions with desired properties, such as, accurate thickness, desirable critical temperature, and good sensitivity at low energy.

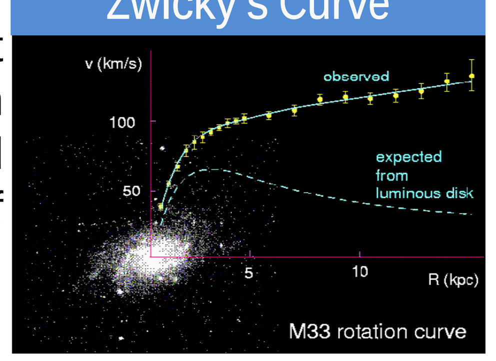
Dark Matter: Introduction

Solar System

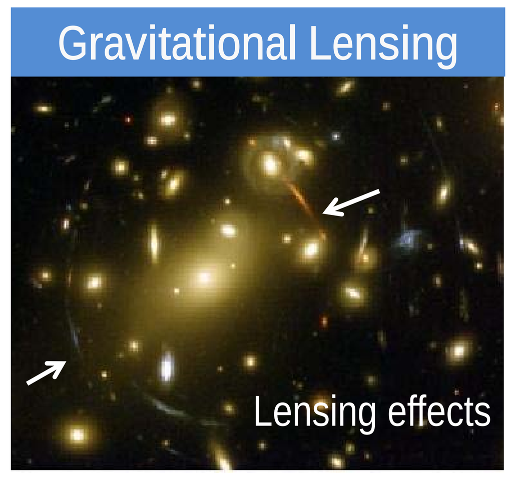


In 1933 Fritz Zwicky observed the velocities of stars in galaxies. If the majority of a galaxies mass is in the center, an application of Newton's laws would imply the speed of the stars on the outside of the galaxy fairly slow, as seen for the planets in our solar system. However, the the outside stars were moving faster than predicted. Zwicky found that there was 400 times more mass than he had originally predicted. He noted that there must be some type of extra, invisible matter in the galaxies.

Zwicky's Curve

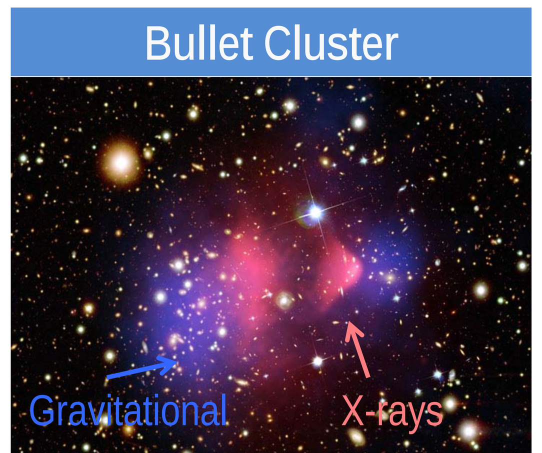


Gravitational Lensing



Matter bends space-time around it, so when a light ray passes by a massive object, it will also bend. This phenomena is called gravitational lensing. Light behind the object will focus to form virtual images in an arc around the object. From this gravitational lensing, the mass of the object can be estimated. It is observed that there is much more matter in the galaxies than visible matter.

Bullet Cluster



Dark matter's presence could be observed with the bullet cluster. Two galaxies passed through one another and the visible matter interacted, emitting x-rays. The bulk of the mass (calculated by lensing) did not emit x-rays. This lead scientists to conclude that galaxies contain more than just visible matter that does not interact with light.

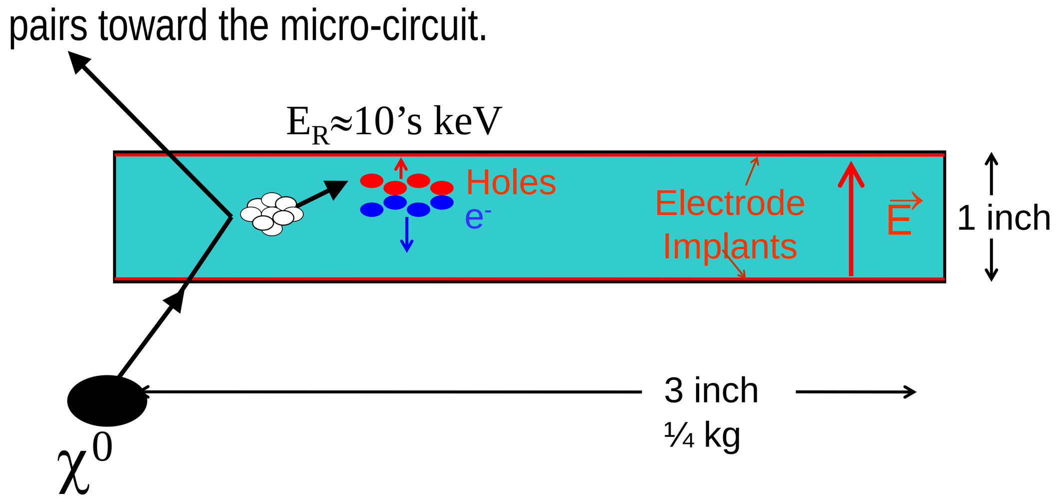
WIMPs

WIMPs (Weakly Interacting Massive Particles) are possible Dark-Matter candidates with mass 10 - 100 GeV. They interact only by the weak nuclear force. "Highly sensitive" detectors are needed to directly detect WIMPs.

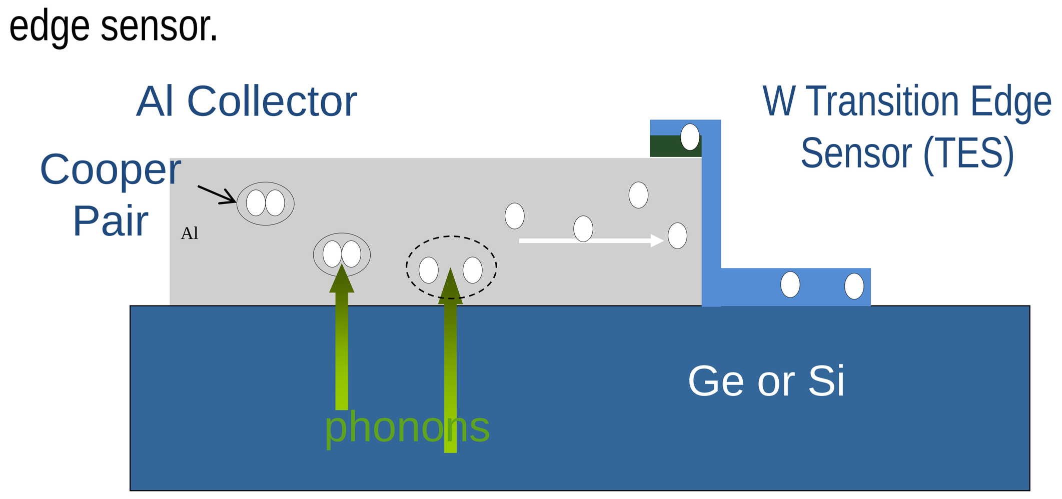
Detectors

ZIP detectors (Z-dependent Ionization and Phonon) are used to detect ionization and phonons. These detectors use patterned micro-circuits on the top and bottom surface of 1 inch thick by 3 inch diameter Germanium crystal and operate at 50 mK.

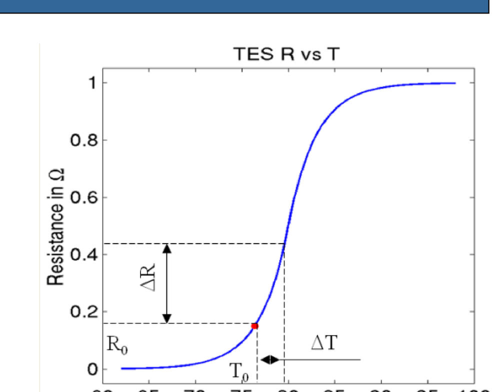
Weak interactions between WIMPs and Germanium nuclei generate electron-hole pairs (ionization) and Phonons (vibration in crystal lattice). To collect ionization signal, an electrical bias is applied across the Germanium which sweeps the electron-hole pairs toward the micro-circuit.



Generated phonons interact with cooper pairs in superconducting aluminum film deposited on both sides of germanium and create quasi-particles, which are then caught by a tungsten transition edge sensor.

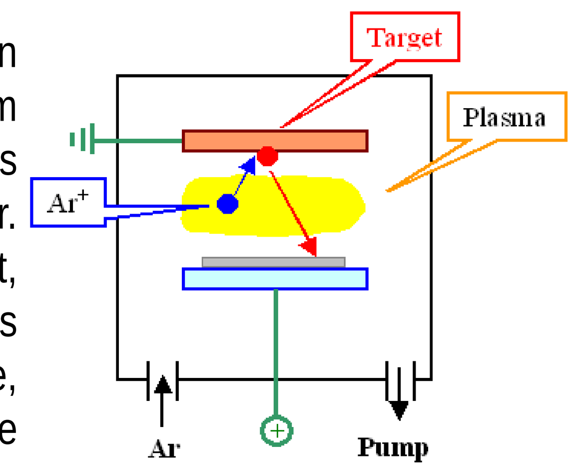


TES sensors held in equilibrium between normal and super conducting temperatures are highly sensitive to the small energy deposit from the quasi-particles.



Texas A&M university aims to improve fabrication and design aspects of ZIP detectors for better, more reliable and speedy production of detectors with least possible variations.

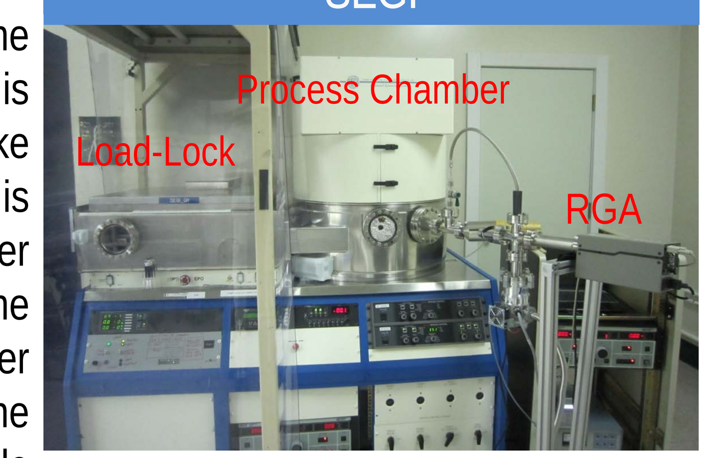
Sputtering



Sputtering is used to deposit thin films onto the Germanium substrate. An argon plasma is struck in the process chamber. Argon ions strike the target, breaking free atoms which gets deposited on the substrate, producing a thin film of the desired material.

Texas A&M uses an automated sputtering system called a SEGI. The SEGI system is computer controlled and has two chambers, the process chamber and the load-lock. The process chamber is where depositions take place and the load-lock is used to transfer substrates. The advantages of computer control comes is the ability to get repeatable depositions with minimal personnel requirement. The advantage of two chambers is that the process chamber is always under vacuum. This minimizes contamination and speeds up the deposition process.

SEGI



Photolithography & Etching

Spin Coater

Contact Aligner

Wet bench (For etching)

After deposition, substrates goes to the photo lab for pattern-formation (etching).

It is spin coated with photo-resist and soft baked. Following, the substrate is put in the contact aligner and lined up with the mask containing the desired features. Then it is exposed to UV and developed. Everything exposed to UV develops off and the resist under the mask stays put.

After transferring features onto the resist layer, it is "hard baked" so it does not dissolve in the etch step. This forms a protective barrier for the etching process. Aluminum and/or tungsten are etched away leaving the desired pattern. Lastly, the photo-resist is stripped and the substrate is ready for inspection.

Sources

S Campbell, *Fabrication Engineering at the Micro- and Nanoscale*, 3rd edition, (Oxford University Press, 2008).

Clow, D.,et al., Ast. J. Lett. 648, L109, (2006).

S.W. Nam, *Development of Phonon-Mediated Cyrogenic Particle Detectors With Electron and Nuclear Recoil Discrimination*, PhD. Thesis, Stanford University, 1998

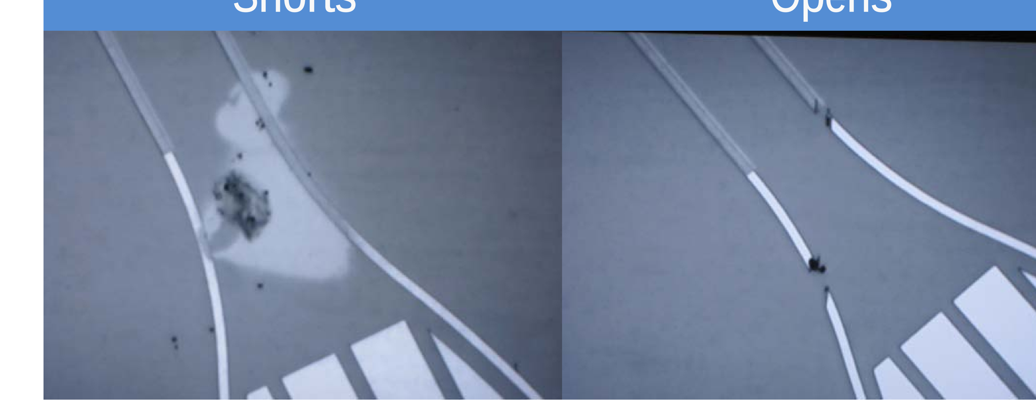
Inspection

Inspection Scope

Substrates need to be optically inspected after deposition, photolithography, and etching processes to check against etch-defects.

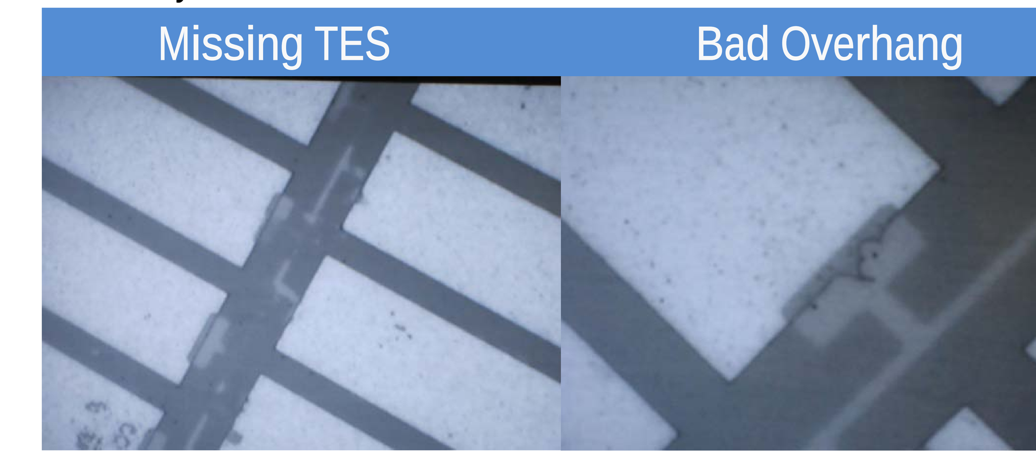
The most common etch defects are "shorts" and "opens." Shorts occur when tungsten or aluminum thin-films were not fully etched between rails. This connects the voltage biases and shorts the circuit. Opens occur when gaps in the bias-rails break open the circuit. This is fixed by wire-bonding the two ends of an "open." Smallness of the circuit features make this very difficult.

Shorts / Opens



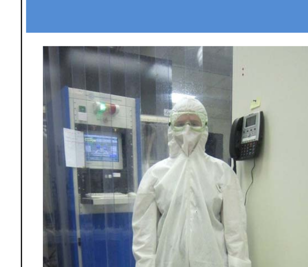
Two not so common defects are missing TES (Transition Edge Sensor) lines and bad overhang. Missing TES lines will cause the specific phonon sensor to malfunction. Bad overhang deteriorates signal transfer to tungsten sensors. Both defects result in unregistered phonons that directly hurt detector efficiency.

Missing TES / Bad Overhang



All substrates must be inspected to ensure none of these defects exist.

Acknowledgements



Rupak Mahaptra	Kristopher Koch
Rusty Harris	Arun Aryasomayajula
Joel Sander	Cyclotron Institute
Mark Platt	Department of Energy
Kunj Prasad	National Science Foundation
Andrew Jastram	Texas A&M University